INTERIM REPORT ON

ACID MINE DRAINAGE CONTROL
IN THE SAND COULEE CREEK AND
BELT CREEK WATERSHEDS, MONTANA

Prepared for
Montana Department of State Lands

By
Thomas J. Osborne
Compiled by: Marek H. Zaluski

MONTANA BUREAU OF MINES AND GEOLOGY

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Interim Report

ACID MINE DRAINAGE CONTROL IN THE SAND COULEE CREEK AND BELT CREEK WATERSHEDS CASCADE COUNTY, MONTANA 1983-1985

INTRODUCTION

This interim report discusses the findings and progress of work on the acid mine drainage control project being conducted by the Montana Bureau of Mines and Geology, Butte, Montana, for the Montana Department of State Lands, Helena, Montana. The project began June 16, 1983 and is scheduled to run through calendar year 1987. The location of work is near the communities of Sand Coulee and Stockett, Montana, approximately 10 miles southeast of Great Falls. Plates 1A and 1B show the location of the study area, test sites and wells. The purpose of this project was to test two site-specific, hydrogeologic techniques of acid mine drainage control. The two methods to be tested were: 1) recharge control by intensified farming of groundwater recharge areas and 2) horizontal or slant drainage wells. The investigations were concentrated within three study areas named after the owners of the land: Chartier site, Johnson site and Takala site. An additional project component was to investigate the extent of groundwater contamination in the alluvial aquifer bordering the lower reaches of Sand Coulee Creek.

PROJECT GOALS

Recharge control

Research on control of dryland salinity by Montana Bureau of Mines and Geology has conclusively demonstrated the effectiveness of intensified farming methods for controlling recharge to shallow groundwater systems.

The goal of the recharge control portion of the project was to implement and monitor a large, field-scale application of agricultural controls to groundwater recharge. Conversion of strip-cropped grain land to alfalfa and re-cropping of small grains were the two techniques used. Both types of changes in the cropping systems were expected to intensify the use of precipitation by the crops, resulting in less water recharging aquifers and, consequently, reducing the acid mine discharge.

Recharge control is being accomplished at two sites--the Chartier ranch and the Johnson ranch. On the Chartier ranch site, 532 acres of land formerly under a crop-fallow rotation system has been converted to an alfalfa-grass mixture. This site sits directly atop one of the largest mines in the region (Old Sand Coulee Mine) and is believed to be a major recharge area. The site on the Johnson ranch involved establishment of a flexible-cropping system on 438 acres of cropland which also serves as a mine recharge area. Monitoring of crop water use, precipitation, groundwater levels and acid mine discharges, allows evaluation of the effectiveness of this system.

Drainage wells

The Morrison coal seam, which was the target of underground coal mining, is usually overlain by 100 to 200 feet of the Kootenai Formation. One or two sandstone beds in the Kootenai are local or regional aquifers and are a source of groundwater leakage to the mines below. The goal of this portion of the project was to find a suitable site for installation of a gravity drainage well which would dewater these aquifers, thereby reducing groundwater inflow to the mine.

The exploration phase has been completed with the identification of at least one favorable test site for which landowner permission was obtained. At least one other site is suitable if landowner permission can be obtained. The initial bid advertisement to drill the drainage well did not yield any applicants. A second effort resulted in a tentative agreement with a driller to install at least one test well on the Chartier ranch sometime in the first six months of 1986. The driller, however, later chose not to attempt the work. The Montana Highway Department has a horizontal drill rig, but declined an offer to do the work. Finally, a firm in Canada, which was willing to do the job, was located. Unfortunately, they requested more than the budgeted amount, and were not authorized to do the work. Eventually, the Montana Department of State Lands cancelled this part of the project.

Alluvial aquifer contamination

Acid mine discharge to Sand Coulee Creek over many years has possibly impacted the groundwater system of the lower valley. Earlier Montana Bureau of Mines and Geology studies (Osborne and others, 1983) demonstrated that most of the creek's flow was lost to seepage during baseflow periods. The quality of water in Sand Coulee Creek is very poor. It is high in iron, aluminum, sulfate and has a pH of 2 to 3. The goal of this portion of the project was to install wells in the lower valley and determine the extent of groundwater contamination, if any.

Twelve shallow wells were installed in four arrays of three each, perpendicular to the creek channel. Monthly water-level measurements have been made and a full set of water-quality samples was collected. Further

monitoring and additional sampling are needed to determine if the observed water quality results from contamination or is typical of the glacio-lacustrine and alluvial sediments that fill the lower valley of Sand Coulee Creek.

DESCRIPTION OF STUDY SITES

Recharge control

Experimental cultivation of an alfalfa-grass stand for groundwater recharge control is being conducted on the Chartier ranch approximately one mile south of Sand Coulee, Montana. A total of 532 acres of cropland on an elevated bench overlying the abandoned coal mines was converted from a small grain-fallow rotation to an alfalfa-grass mixture. The available maps of the abandoned mines show that the test site is directly above the abandoned mines. The vertical distance between the ground surface and mines is typically 180 to 200 feet. The upland area of the test site is bordered by Cottonwood Creek on the east and Mining Coulee on the west. These drainages receive the groundwater and acid mine discharge from the study site area.

A second study site was established to test the effectiveness of a flexible grain-cropping system in recharge control. It is within the Johnson ranch, just east of the community of Tracy. At this site, 438 acres of land formerly on a crop-fallow farming system were incorporated in a flexible cropping system where small grains are planted every year if soil moisture permits, and rotated between wheat and barley. This site is on an upland bench with the abandoned coal mines lying approximately 180 to 200 feet below land surface. The valley of Sand Coulee Creek and its tributary coulees form the western and northern boundaries of the bench. Upland areas continue to the east and south of the study site.

The analysis of agricultural recharge control through the years 1984 and 1985 is presented in Appendix IA and IB of this report.

Drainage wells

Three sites were investigated for suitability as a test site for a horizontal or slant drainage well. These are the Chartier ranch, Johnson ranch (both previously described) and the Takala ranch about 2 miles southeast of Stockett, Montana. Vertical test holes were drilled on these sites to determine the geologic structure and the geometry and occurrence of aquifers. Wells were installed to monitor groundwater heads and recharge. Heads in the wells at each site were used to map directions of groundwater flow.

A primary drilling site (T. 19 N., R. 4 E., sec. 26 BBCA,) was selected on the Chartier ranch near MBMG well C8. The well-head site is in the bottom of Sand Coulee Creek about 300 feet northeast of the old homestead building. The axis of the drillhole will be southwesterly towards well C8. The basal Kootenai sandstone aquifer is confined at this point, and a slant well about 450 feet in length should allow the head in the well to come very close to ground surface, permitting a siphon discharge system to be set up. Although this site is approximately 3,300 feet upgradient from the closest boundary of the Upper Carbon Mine, the hydrogeologic conditions make it a favorable test site. The drilling distance will be considerably shorter than alternate locations on the Chartier, Johnson or Takala study sites.

Alluvial aquifer contamination

The area of investigation of the Lower Sand Coulee Creek valley extends from the Johnson ranch about 2 miles north of Tracy to about 2 miles upstream of the mouth of Sand Coulee Creek. In all, 12 wells were drilled, three each in four arrays perpendicular to the creek channel, as shown on Plate 1A. Monitoring and sampling of water quality from these wells was thought to give a good indication of the contamination potential throughout the ancestral buried Missouri River valley now occupied, in part, by Sand Coulee Creek.

Explanation of the symbols used

In order to minimize confusion, the same symbols which were used in reports by previous investigators for numbering the acid mine discharge sites are also used here.

Symbols used for the wells and piezometers drilled for this project at Chartier, Johnson and Takala sites consist of three parts:

- A letter C, J or T (after the first letter of the name of the owner);
- A number from 1 to 11 which indicates the drilling site at each study area;
- A two- or three-digit number indicating the total depth of the well;

note - there may be as many as four wells of different total depth at any one drilling site.

All symbols used for the additional wells in the alluvial aquifer of lower reaches of Sand Coulee Creek begin with a "Q" (Quaternary). This is followed by a letter A, B, C or D, indicating an array. This, in turn, is followed by a number 1, 2 or 3, indicating a specific well.

REGIONAL GEOLOGY

The hydrogeology of the project area is strongly related to the geology and, therefore, geological mapping of the Southeast Great Falls and Stockett quadrangles, Montana, scale 1:24,000, was done by the Montana Bureau of Mines and Geology. The geologic maps (Plate 2A and 2B) are presented as is an explanation for these maps (Appendix II). The geology of the area is also described below.

General

Cretaceous, Jurassic and Mississippian sedimentary rocks crop out in the project area. Prior to the Jurassic, strata were tilted southward, and erosion removed all of the sediments that had been deposited down to the Mississippian Mission Canyon Limestone. The Jurassic Piper and Rierdon formations of the Ellis Group were not deposited in the area because of the influence of the Belt arch, a topographic high that was present at that time. Consequently, the Jurassic Swift Formation of the Ellis Group rests unconformably on the Mission Canyon Limestone.

The Morrison Formation conformably overlies the Swift and contains a thin zone of highly volatile bituminous coal (Daniel and others, 1985) at its top. This coal was the target of mining activity in the area beginning in the 1880's. The Cretaceous Kootenai Formation, which is channeled into the upper Morrison, is the most widespread unit in the area and contains the principal aquifers leaking water to abandoned coal mines in the underlying Morrison Formation. The Kootenai is overlain by the basal sandstone of the Cretaceous Blackleaf Formation.

Structure

The regional dip of 1.5°, $N35^{\circ}W$ (Daniel and others, 1986) is about 100 feet per mile. A series of small, roughly en echelon folds are superimposed on, and have axes generally perpendicular to, the regional dip. The vertical amplitude of these folds typically varies from 20 to 200 feet; wavelengths are on the order of a few thousand feet.

No major faults were mapped in the project area, however, numerous small faults with displacement from several inches to several feet were observed in outcrops. In addition, a detailed subsurface map of the Giffen Mine south of Stockett indicates that numerous small faults were evident in the mine workings. Several faults apparently were large enough to have impeded the progress of mining.

A pronounced northeast trend of stream drainages and vertical joints and fractures occurs in the area. Over 80 northeast-trending lineal drainage features of 0.5 miles or more in length were located within the Stockett 15-minute topographic quadrangle. Approximately 25 lineal drainage features trending northwest-southeast, roughly perpendicular to the primary trend, were also identified.

The average orientation of poles to vertical joints in the basal Kootenai sandstone was mapped in detail at two sites in the project area. A total of eighty-three measurements was taken. One site had average joint orientations of $N35^{\circ}E$ and $N56^{\circ}W$. The second site had average joint orientations of $N44^{\circ}E$ and $N50^{\circ}W$. Measurements of small-scale jointing correlates well with large-scale drainage orientation.

Stratigraphy

The Mission Canyon Limestone (Mississippian) of the Madison Group is the oldest rock exposed in the study area. It is dominantly medium gray micrite containing stromatolites, solution breccia and black chert nodules and beds up to 3 inches thick. Only the upper 100 feet of this formation are exposed. The rock forms cliffs along Sand Coulee Creek east of Stockett.

The Swift Formation (Jurassic) of the Ellis Group overlies the Mission Canyon with an angular unconformity of a few degrees. It is an orangish-brown-weathering, gray or tan calcareous, glauconitic fine- to coarse-grained sandstone containing interbeds of shale and chert-pebble conglomerate. The conglomeratic scour base contains rounded, black chert pebbles and subrounded to subangular clasts of Mission Canyon limestone up to large cobble size. Thickness of the Swift Formation ranges from 4 to about 40 feet.

The Morrison Formation (Jurassic) conformably overlies the Swift and is dominantly greenish-gray mudstone and shale with interbedded lenses and beds of gray micrite and fine- to medium-grained calcareous, thin-bedded, yellowish-brown-weathering limonitic sandstone. The top of the formation contains a 4- to 15-foot zone of black shale and bituminous coal overlying a transitional gray shale. Coal ranges from a few inches to 15 feet thick and occurs as one to three beds separated by shale, sandstone or siltstone partings. Thickness of the Morrison Formation ranges from 80 to 200 feet.

The Kootenai Formation (Lower Cretaceous) disconformably overlies the Morrison and is subdivided into five informal members (Kk_1-Kk_5) in this report. The basal member (Kk_1) forms the roof of most coal mines in the

area and also serves as an aquifer. It is dominantly a resistant, festoon-crossbedded, moderately well-sorted quartz arenite with 20-50 percent black, dark and light gray chert. Coarse-grained sandstone, chert-granule conglomerate or chert-pebble conglomerate occurs at the scour base, typically with abundant rip-up clasts of coal, plant fragments and impressions, and occasional cobble-size chert clasts. Boulder and cobble conglomerate occurs in local zones at the base with rounded cobbles of chert and subrounded to subangular boulders of sandstone. Grain size fines upward, with the upper part of the member generally fine to medium grained.

The second member (Kk_2) contains two facies. One (Kk_{2B}) is dominantly resistant red mudstone which frequently acts as an aquitard separating the aquifers above and below. It contains dense gray micrite and argillaceous tan-gray micrite concretions which laterally become lenticular, irregular beds. Thin, lenticular chert-rich quartz arenite beds occur locally. The second facies (Kk_{2A}) is variable. In Sand and Mining Coulees it consists dominantly of quartz arenite similar in lithology and sedimentary structures to the basal member (but less cemented) and interbedded with light gray or yellow-brown calcareous mudstone. In the Sand Coulee, Centerville, Number Seven area and in Mining Coulee, the facies contains a bed of fine-grained, planar-bedded, light-gray sandstone with red or purple mottling or Leisegang banding near the base, and light-gray sandstone beds with medium to coarse, angular, black and reddish-orange chert and light-gray quartz grains supported in a matrix of fine-grained sand or clay. At Goon and Walker Coulees, the second facies contains interbedded lithologies of the basal member, the second member red mudstone facies, the third member and greenish-gray shale.

The third member (Kk_3) is often an aquifer and, especially south of Stockett, yields modest quantities of excellent quality groundwater to springs and wells. It is channeled into the upper part of the second member and rests disconformably on the first member near Centerville. It is well sorted, resistant quartz arenite generally with about 90 percent quartz and interspersed limonite specks and 2 percent white matrix clay. Primary sedimentary structures include planar-tabular crossbedding and sinuous and straight-crested wave and interference ripple marks. Abundant intervebrate trace fossils occur on bedding surfaces and within beds.

The fourth member (Kk_4) is red to maroon, fine- to medium-grained, micaceous, argillaceous, platy-bedded litharenite rhythmically interbedded with red mudstone. Basal contact is transitional with the third member and contains interbedded gray or red siltstone and mudstone. Low amplitude ripple marks commonly occur on bedding surfaces. Small fragments of plants are abundant, and plant impressions are present locally on bedding surfaces.

The fifth member (Kk_5) is dominantly a red mudstone containing lenses of sandstone and limestone. A persistant zone of ostracod-rich limestone beds occurs at the base and is overlain by dark fissile shale and fine-grained sandstone. This is overlain by claystone and siltstone with stringers of lignite. Lenticular beds of sandstone overlie the lignitic zone. The uppermost part of the member consists of massive, color-banded, greenish-gray, purple, reddish-orange and maroon mudstone with lenses of fine- to medium-grained trough-crossbedded, greenish-gray-weathering sandstone. The entire Kootenai Formation is about 400 feet thick.

The Blackleaf Formation (Lower Cretaceous) of the Colorado Group is the uppermost bedrock unit in the area. Only a portion of the basal sandstone

is exposed. It is a medium-grained, thin- to medium-bedded, mature quartz arenite with abundant ripple marks and invertebrate trace fossils. About 100 feet of this formation are exposed in project area.

Unconsolidated Quaternary deposits overlie the bedrock. These include fluvial sand, silt and clay, windblown sand, older alluvial terrace deposits, colluvium, landslide deposits and lacustrine silt and clay in the buried Missouri River channel. Generally, the Quaternary deposits are relatively thin, usually 30 feet or less in the small coulees. However, the glacio-lacustrine sediments in the ancestral Missouri channel exceed 300 feet in thickness.

REGIONAL HYDROGEOLOGY

The occurrence and movement of groundwater near Sand Coulee and Stockett is controlled primarily by geologic structure, stratigraphy and topography at the regional and local levels. Although this project emphasized several local areas, hydrogeologic information relevant to the region was also obtained.

Previous studies

An overview of the regional hydrogeology can be obtained from previous reports. Fisher (1909) conducted the first comprehensive field geologic and hydrogeologic investigation of the Great Falls region, with field work being done in 1906. Although coal mining had been in progress for about 20 years already, he did not mention any acid mine drainage problems. He did, however, conduct a thorough well and spring inventory. Fisher's most important conclusions were that the basal Kootenai sandstone (Cretaceous) and Flood

Sandstone of the Colorado Group (Cretaceous) were the two most consistent aquifers for yielding water to domestic wells and springs. He noted that springs were more reliable than wells in the Kootenai sandstone aquifers of the Sand Coulee area. In addition, he stated that in the Sand Coulee to Stockett area, the Madison Group limestone generally appears to be dry in its upper part. This was confirmed by a number of wells which had been drilled into the Madison Group limestone and invariably failed to find water.

The geology and groundwater resources of the Stockett to Smith River area were described by Goers (1968) in a master's thesis at the University of Montana. He recognized the extensive karstification of the Madison Group limestone in the area and reported hearing water "running" in certain wells and that these wells blow and suck air in unison. He indicated that the sandstone of the Swift Formation (Jurassic) was not an important aquifer in the region because of the lack of significant direct meteoric recharge or up-dip recharge areas. Goers reported that the basal Kootenai sandstone was the most utilized aquifer in the area. However, he recognized that the aquifer may be dewatered by the abandoned mines in the Morrison coal underlying the Kootenai.

Walker (1974) completed a Ph.D. dissertation at the University of Montana entitled, "Stratigraphy and Depositional Environments of the Morrison and Kootenai Formations in the Great Falls Area, Central Montana". He explained the stratigraphy of the Kootenai Formation in detail, correlating the sandstone outcrops in the Great Falls area to known oil producing beds in the Sweetgrass arch region 80 miles to the northwest. He described the geometry of the quartzose sandstone (Kk_3 or Sunburst equivalent) as shoe

string-like bodies up to 40 feet thick, one-half mile wide and 7 miles long, or as smaller sheet-like bodies. Like Goers, he described the basal Kootenai Sandstone (Kk_1 or Third Cat Creek equivalent) as sheet-like. He identified the regional dip as northwesterly, ranging from 55 to 120 feet per mile. Walker differed from Fisher and Goers in rating the importance of aquifers in the area. Being primarily concerned with the area north of T. 19 N., Walker stated that sandstone in the Swift Formation and sand beds in the buried ancestral Missouri River channel were the best aquifers. He reasoned that the cause of this was a donor-receptor interconnection between the Madison Group limestone (donor) and these aquifers (receptors) in which the Swift sandstone aquifer and the sediments filling the old Missouri River channel were recharged (under artesian pressure) from the underlying Madison Group limestone aquifer. Walker felt that most recharge to bedrock aquifers occurred in the foothills region south of Stockett, but recognized that local sources were also possible. He recognized the potential contamination of the Sand Coulee Creek alluvium from acid mine drainage, but felt that contamination would go no deeper because of the likelihood of upward gradients from the Madison-Swift aquifer into the alluvium.

Westech/Hydrometrics (1982) produced a report to the Montana Department of State Lands. The report included an inventory of acid mine discharge sources, some periodic measurements of flow and water quality and contained a potentiometric map of heads composited from all Kootenai sandstone aquifers. This map also showed the relationships of acid mine discharges to precipitation trends.

Osborne, Donovan and Sonderegger (1983) with the Montana Bureau of Mines and Geology produced a report under contract to the Montana Water

Resources Research Center. They investigated the characteristics of the acid mine discharges and interaction between surface water and groundwater in the Stockett-Sand Coulee area (south of T. 20 N.). A regional inventory of 46 domestic wells was conducted. The inventory indicated that about one-half of the local residents obtained their water supplies from the Madison aquifer. Most alluvial groundwater in the area was found to be contaminated from acid mine drainage. The authors also suggested that seven of sixteen wells sampled were contaminated to some extent by downward leaking acid mine drainage; these wells had been completed in Jurassic sandstone aquifers or the Madison Group limestone. Osborne and others (1983) reported that stream leakage, natural downward leakage and well bores all distribute acid mine drainage to the Madison aquifer due to downward hydraulic gradient in this area. By modeling the mixing of acid mine drainage with uncontaminated groundwater from Madison Group limestone, they closely reproduced observed Madison aquifer water chemistry.

Wilke (1983) of the U.S. Geological Survey, published an appraisal of bedrock aquifers in northern Cascade County, Montana. Her report included a well inventory and results of water-quality sampling primarily around Great Falls. She regarded the Madison-Swift aquifer and overlying Kootenai sandstone aquifers as being interconnected in the Great Falls area, and all essentially at water-table conditions. Water-chemistry data also indicated that mixing of groundwater from various aquifers was occurring. Wilke postulated that the cause of the vertical mixing was the extensive fracturing and jointing of bedrock lying along the crest of the South arch, a continuation of the Sweetgrass arch that trends southeasterly through Great Falls.

Significant regional hydrogeologic findings

The following synopsis presents the important findings of this project relative to regional hydrogeologic issues.

The extent and hydrogeologic importance of geologic structures

Contours of the top of the Morrison coal bed from Stockett to Sand Coulee are shown in Figure 1. The regional dip is generally 1.5 degrees, N35^{o}W. The dip has a considerable influence on the occurrence of groundwater in the region. Generally, the upgradient side of aquifers that are truncated by coulees are unsaturated along the outcrop. The downgradient side is where natural springs and acid mine discharge frequently occurs.

This investigation also showed that location of specific aquifer discharge points can be controlled by variations in the local structure. Several acid mine discharges and freshwater springs were found to be located near the axis of small synclines.

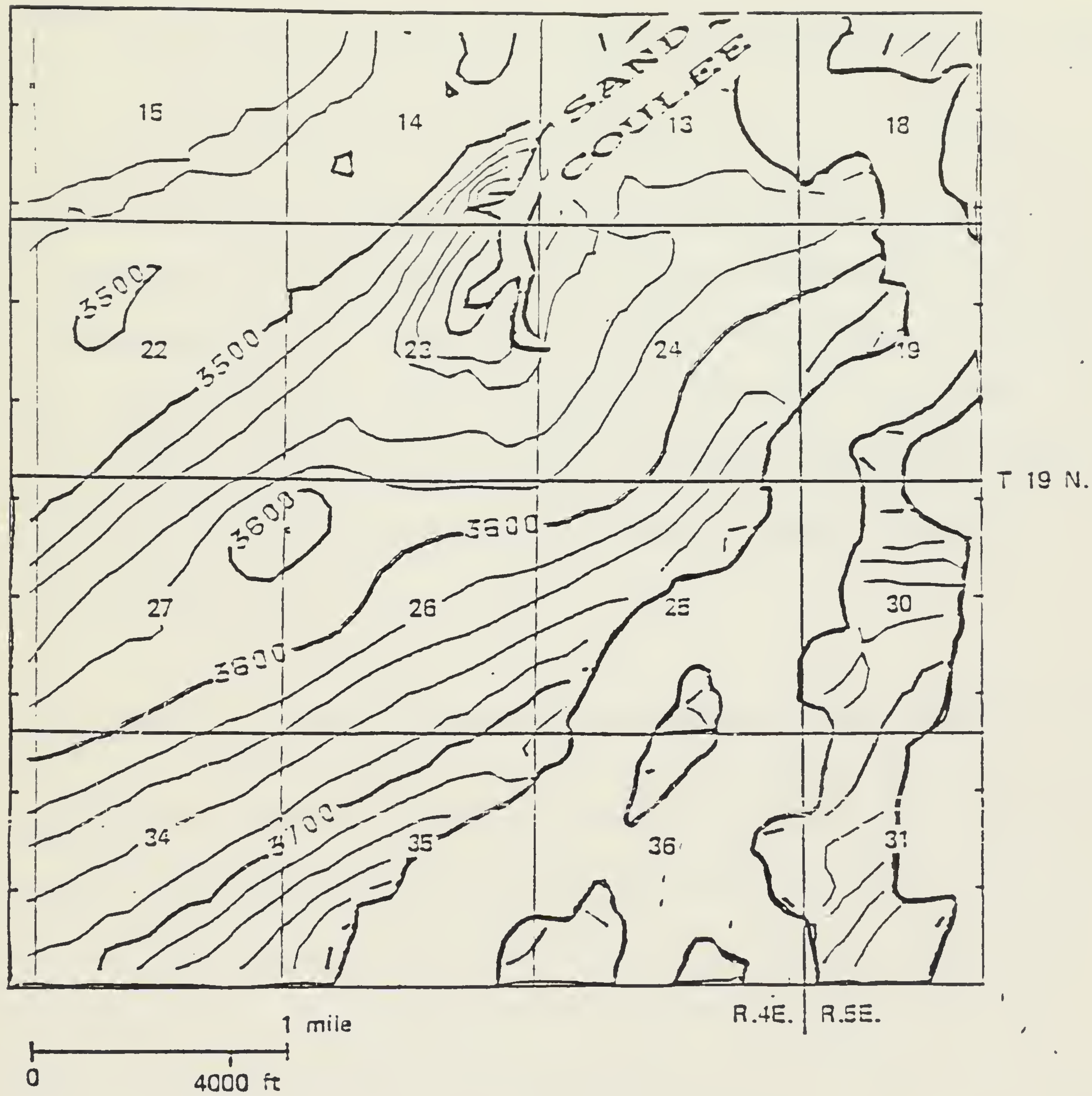
Drainage orientation with prevailing fracture and joint trends

Marked preferential orientation of drainages exists in the region. More than 100 drainage segments having a northeast-southwest trend, and about 50 segments having a northwest-southeast trend were identified in the area covered by the Stockett 15-minute topographic map. Plots of 83 joints in the basal Kootenai sandstone, as measured in the field at two sites, indicated two predominant orientations: N40^{o}E and N53^{o}W. Observations in the field and in one abandoned mine near Stockett indicated that the vertical joints and fractures are generally continuous linear features

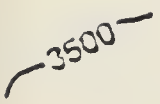
Fig. 1

Contours of the top of the Morrison coal bed

south of Sand Coulee, Montana



Legend



Top of the coal isoline, feet(MSL)


Limits of the coal bed

extending from the surface, across the bedding in the Kootenai Formation through the Jurassic section. Joints and fractures are ubiquitous in the region and undoubtedly serve as pathways for surficial drainage development and groundwater recharge.

Variations of lithology, thickness and extent of Kootenai sandstone aquifers

Although other geological studies have pointed out that variations exist in the lithology, thickness and extent of Kootenai sub-units (Fisher, Goers), the mapping and drilling done through this project identified these factors specifically in the Stockett-Sand Coulee area. The basal Kootenai sandstone (Kk_1) was found to thin to only two feet thick near Stockett and was not an aquifer. The lithology of the Kk_2 mudstone unit graded from red to green mudstone and from limestone interbeds to sandstone interbeds from Sand Coulee to Stockett.

Quantification of acid mine drainage and relationship with precipitation

Acid Mine drainage is a regional problem in the Great Falls-Lewistown coal field. The continuous-discharge hydrographs and precipitation data collected in this project allow calculation of effective recharge rates, total discharge and the variability of discharge. For mines which are believed to receive recharge of water primarily through vertical infiltration, the ratio of average annual discharge-to-mine area was in the range of 0.09 to 0.27 ft/yr (2.7-8.2 cm/yr). Mines receiving recharge from both vertical infiltration and regional flow systems had discharge-to-mine area ratios of 0.56 to 2.4 ft/yr (17-73 cm/yr). These data are summarized in Table 1.

TABLE 1 Relationship of average annual volumetric discharge to mine area for Sand Coulee mines

Mine	1983-85 Average discharge acre-feet	Mine area acres	Ratio of average discharge to area
AS01	212.	89.3	2.37
CS09	43.4	218.	0.20
AS08	128.*	1466.	0.09
AS07	77.9	637.	0.12
AS02	14.6	15.8	0.92
CS01	106.	190.	0.56
SCM7	44.3	164.	0.27

* The 1983 and 1984 water year volumes were estimated by ratio with AS01 for 1985

Regional groundwater impacts from dewatering by mines

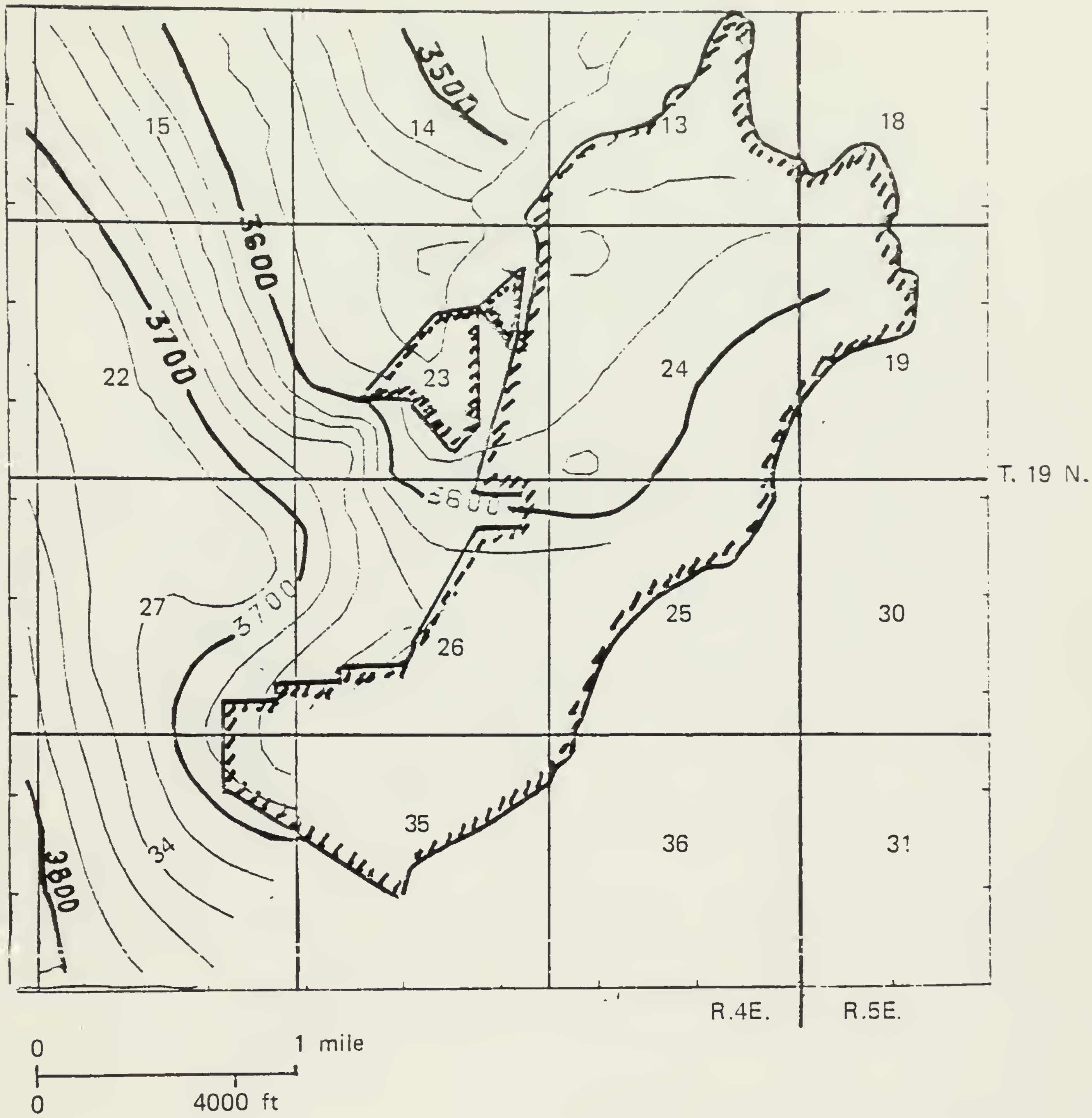
The presence of large, abandoned underground coal mines south of Sand Coulee apparently has produced a large change in the regional groundwater flow system. The under-drainage of the basal Kootenai sandstone aquifer by the abandoned mines has diverted the groundwater flow, which likely discharged to Sand Coulee and Mining Coulee prior to mining. Figure 2 shows the deflection in the equipotential lines caused by the abandoned mines. The dewatering of the basal Kootenai aquifer has led to a large area of thinly saturated or unsaturated sandstone aquifer underlying the bench south of Sand Coulee and west of Stockett. Figure 3 shows the general areas in which the basal Kootenai aquifer is artesian, water table and unsaturated.

Water-level fluctuations in the Kootenai aquifers

Apparent recharge rates to the two primary Kootenai aquifers, the basal sandstone (Kk_1) and quartzose sandstone (Kk_3), were measured with recorders and periodic monitoring: the maximum observed water-table rise in the Kk_3 sandstone was 8.3 ft between October and December 1984; it occurred in well C1-47. A gradual rise of 5.3 ft was observed from December 1984 through April 1985 in well C2-40 bordering an alfalfa field. Water levels in wells completed in the Kk_3 unit showed general declines during most of water year 1985 because of the prolonged drought. Following the dramatic increase in precipitation beginning in August 1985, wells C2-40 and C3-5 showed 0.5 and 1.0 ft of water-table rise, respectively, from November 1985 to June 1986. Well L1-40, also in the Kk_3 unit, indicated a 1.6 ft rise in the water table between December 1985 and June 1986.

Potentiometric head of the basal Kootenai aquifer (Kk_1)

south of Sand Coulee, Montana



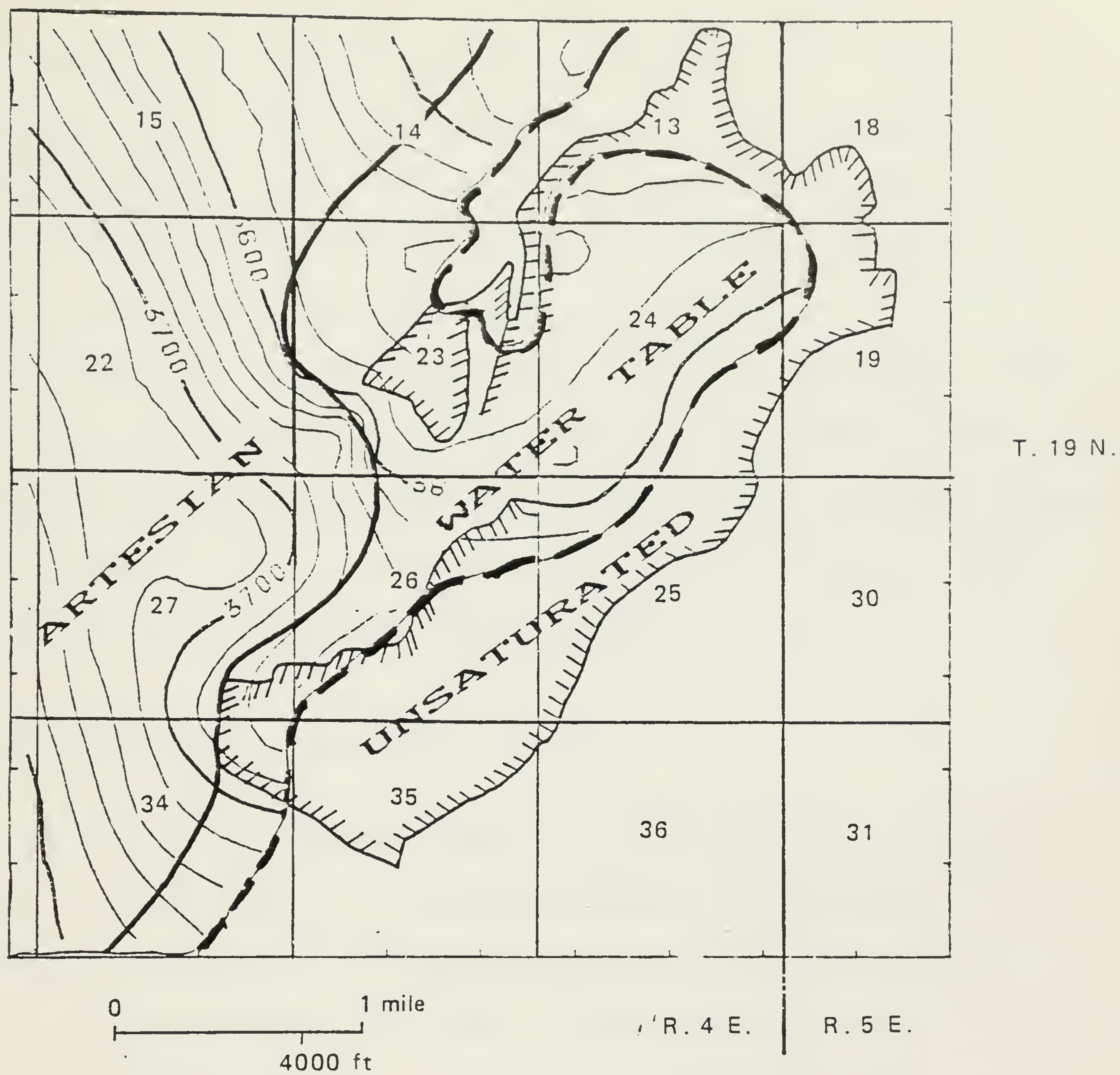
Legend

Mined Area

3600 Potentiometric surface, feet (MSL)

Fig. 3

Aquifer status of the basal Kootenai sandstone (Kk_1)
south of Sand Coulee, Montana



Legend

3600 Isoline of potentiometric surface, feet (MSL)

Downgradient limit of artesian aquifer

Downgradient limit of water-table aquifer

Mine area

Among the deeper wells completed in the basal sandstone (Kk_1), well C-8 indicated an 18 ft water-table rise between April and May 1984. The deep wells generally indicated static or falling potentiometric head during 1985. In several cases they responded dramatically to the heavy precipitation of August and September 1985. For example, the water level in well C1-198 rose about 40 ft during November and December 1985, and the water level in well T1-172 rose over 50 ft between February and March 1986.

By themselves, the water-level changes are of limited value in determining the volume of recharge to the Kootenai aquifers because of the limited area over which well response is representative. The best recharge volume estimates would be made by analysis of acid mine discharge hydrographs, precipitation and water-level changes.

Inter-aquifer hydraulic gradients

Installation of nested observation wells and piezometers in various aquifers allowed estimation of average vertical hydraulic gradients between aquifers. In all cases for Kootenai Formation and coal mine aquifers, hydraulic heads decreased with depth. Table 2 summarizes the vertical hydraulic gradients calculated as a ratio of average head difference and vertical distance between centers of well screens for a given pair of aquifers.

TABLE 2 Vertical hydraulic gradients

Well Pair	Aquifers	Average vertical gradient Ft/Ft	Well type
C1-47/C1-198	Kk_3/Kk_1	1.07	O/O
C5-13/C5-64	Qal/Kk_1	0.73	P/O
C5-64/C5-75	Kk_1/Mine	0.95	O/O
C6-45/C6-197	Kk_3/Kk_1	1.03	O/O
L1-40/L1-172	Kk_3/Kk_1	0.63	O/O
J1-47/J1-117	Kk_1/Kk_2	0.96	P/P
J4-50/J4-173	Kk_3/Kk_1	0.92	P/P

O = Observation Well   P = Piezometer

It should be noted that some of the wells used in Table 2 are observation wells which are screened for all or most of the aquifer thickness; gradients determined from these wells are only approximate.

The vertical gradients (Table 2) are rather large because, in most cases, vertical flow must pass through the Kk_2 mudstone unit, which is an aquitard between the quartzose sandstone (Kk_3) and basal Kootenai sandstone (Kk_1). The gradients are quite consistent, with the smallest value (0.63) calculated from the only well-nest completed in an artesian portion of the Kk_1 aquifer. This suggests that, as expected, mine workings dewatered the Kk_1 aquifer, lowering the potentiometric head and causing larger vertical gradients.

Upper Carbon Mine - AS01 (Chartier site)

Characteristics

It is assumed that the Upper Carbon Mine (Plate 1A) is dewatered by the acid mine discharge AS01 located at the Chartier ranch.

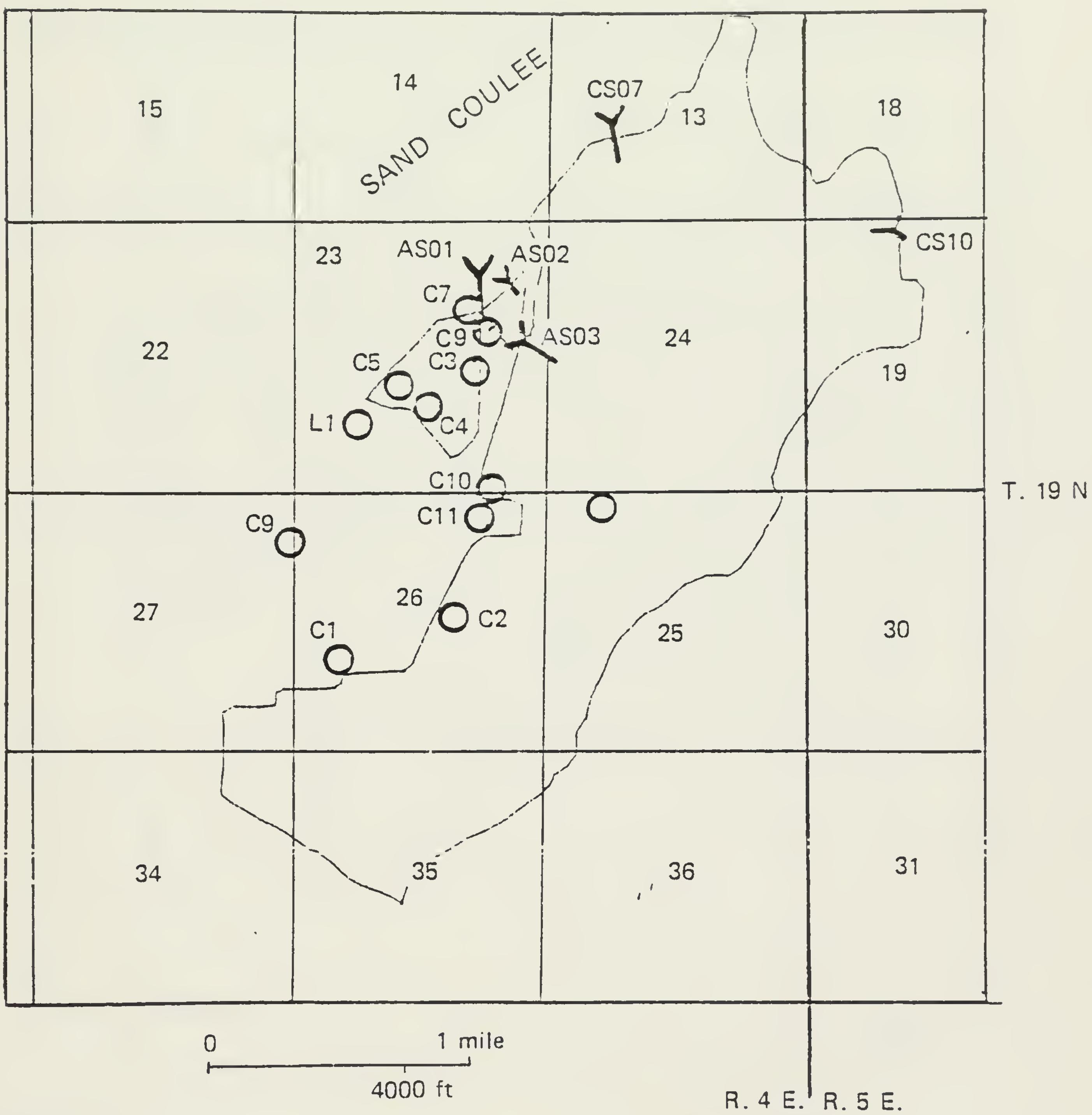
TABLE 3 Characteristics of the acid mine discharge AS01

Mine area	89 acres
Average discharge	0.029 ft^3/sec
Observed range	0.05 - 1.11 ft^3/sec
pH range	2.21 - 3.01
Specific conductance range	4679 - 5349 usiemens/cm

The distinguishing feature at the Upper Carbon Mine is its large average discharge relative to its area. The reason for this is the proximity of the mine to a regional groundwater flow system in the basal Kootenai sandstone (Kk_1) aquifer. Figure 4 is a well and acid discharge location map, whereas Figure 5 is a map of the potentiometric head of the Kk_1 aquifer near the Upper Carbon Mine. The Upper Carbon Mine intercepts groundwater discharge from a large unmined recharge area to the southwest. A large zone of artesian head (Figure 3) occurs just upgradient from the Upper Carbon Mine and is the driving force for the large rate of discharge. The head declines rapidly at the edge of the Upper Carbon Mine and other mines in the vicinity such that the aquifer is depressurized to a water-table condition.

Fig. 4

Well and acid discharge location map, Chartier site, Sand Coulee, Montana



Legend

Y Acid mine discharge

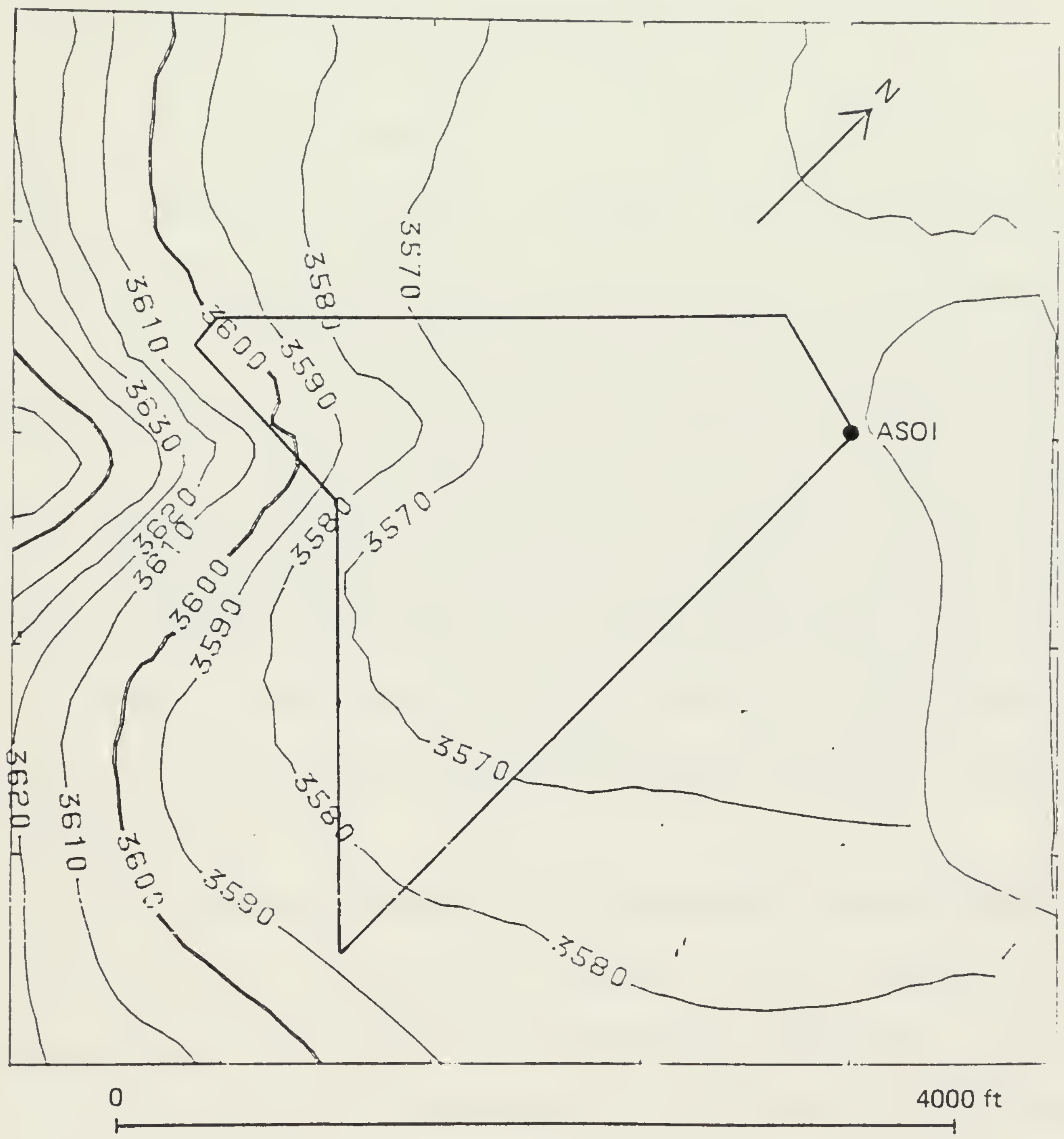
O Well site

Limits of the Old Sand Coulee Mine

C2 Well site

AS02 Discharge number

Potentiometric head of the basal Kootenai aquifer (Kk_1), Upper Carbon Mine area



Legend

Limits of the Upper Carbon Mine located in section 23, T.19 N., R. 5E.

3600 Isoline of potentiometric surface, feet (MSL)

AS01 Acid mine discharge site

The data from several wells (C3, C4, C9) confirmed that the Kk_1 aquifer is mostly dewatered, usually having less than 5 feet of saturated thickness directly over the mines. Much of the structurally high side of the Kk_1 aquifer adjacent to Cottonwood Creek is fully dewatered except during intense recharge periods. A three-dimensional illustration of the configuration of the top of the Morrison coal bed is shown in Figure 6.

Recharge to the Upper Carbon Mine was found to be concentrated along Sand Coulee. This condition results from both geologic and hydrologic factors. The general geology of the site is illustrated in cross section in Figure 7. The coulee is incised approximately 100 feet relative to the surrounding benchland, resulting in thinner overburden (within the coulees) to attenuate water recharge. In addition, the coulees and drainages of the region have a strong directional orientation along the dominant poles of rock fracturing (NE-SW and NW-SE). Hydraulic conductivity of all rock units should be greater in the coulees because of enhanced fracturing and jointing. The limited data available tends to support the idea of preferential permeability in coulees.

A slug test conducted on well C5-64, completed in the Kk_1 aquifer, gave a horizontal hydraulic conductivity of 5.7×10^{-4} ft/sec. By contrast, low-discharge pumping tests conducted by Hydrometrics (1982) gave horizontal conductivities of 4.3×10^{-5} ft/sec and 5.0×10^{-5} ft/sec in the Morrison coal bed and 2.2×10^{-6} ft/sec in the Kk_1 sandstone aquifer. Extensive fractures were encountered while drilling wells at site C7 in Sand Coulee near the AS01 mine discharge. Well C7-47, completed in fractured shale 30 feet beneath the bottom of the Morrison coal bed, produced over 30 gallons per minute (gpm) of mine water (pH about 4). This indicates that fractures

Fig. 6

Configuration of the top of the Morrison coal bed ,

Upper Carbon Mine area

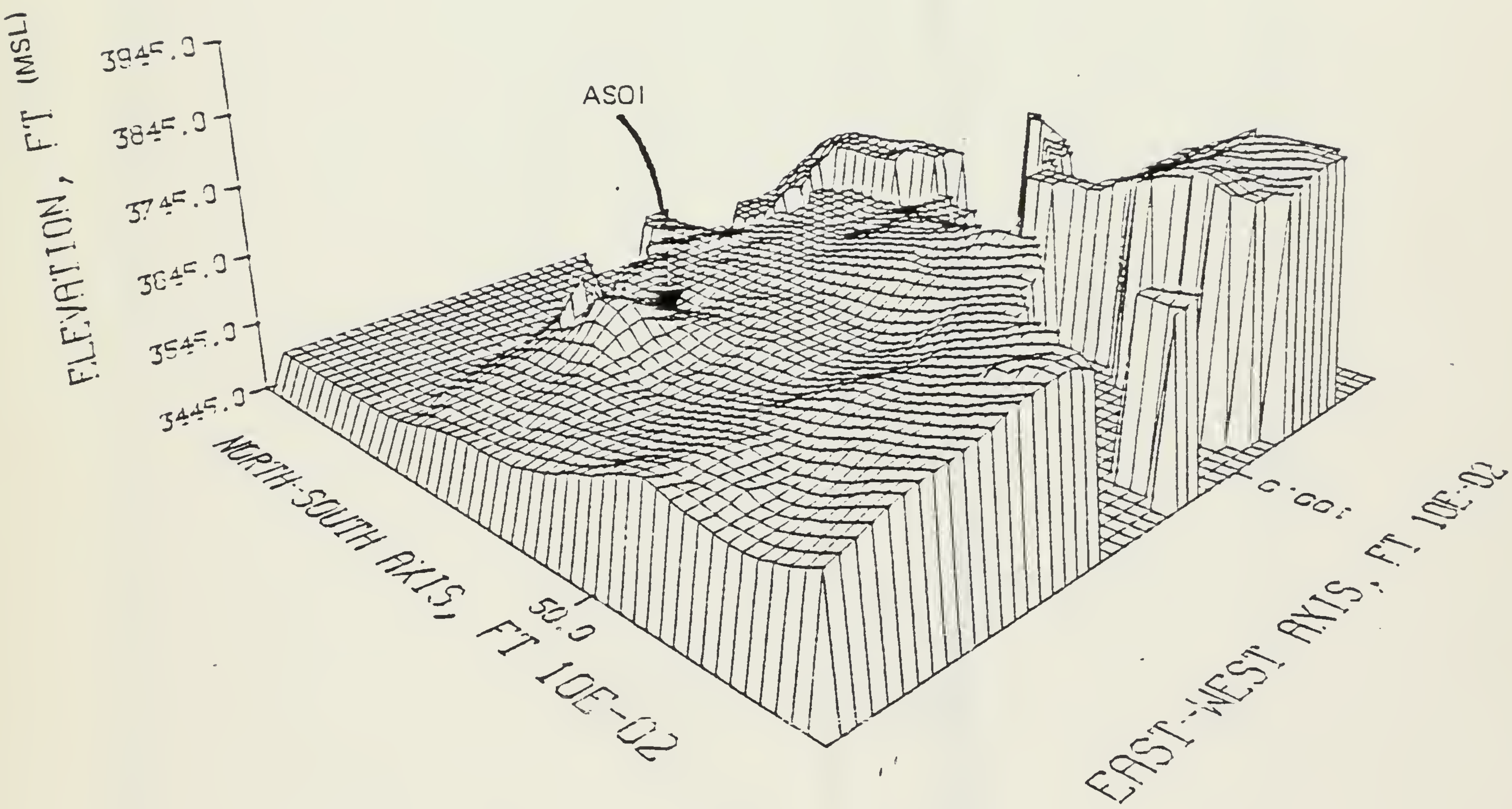
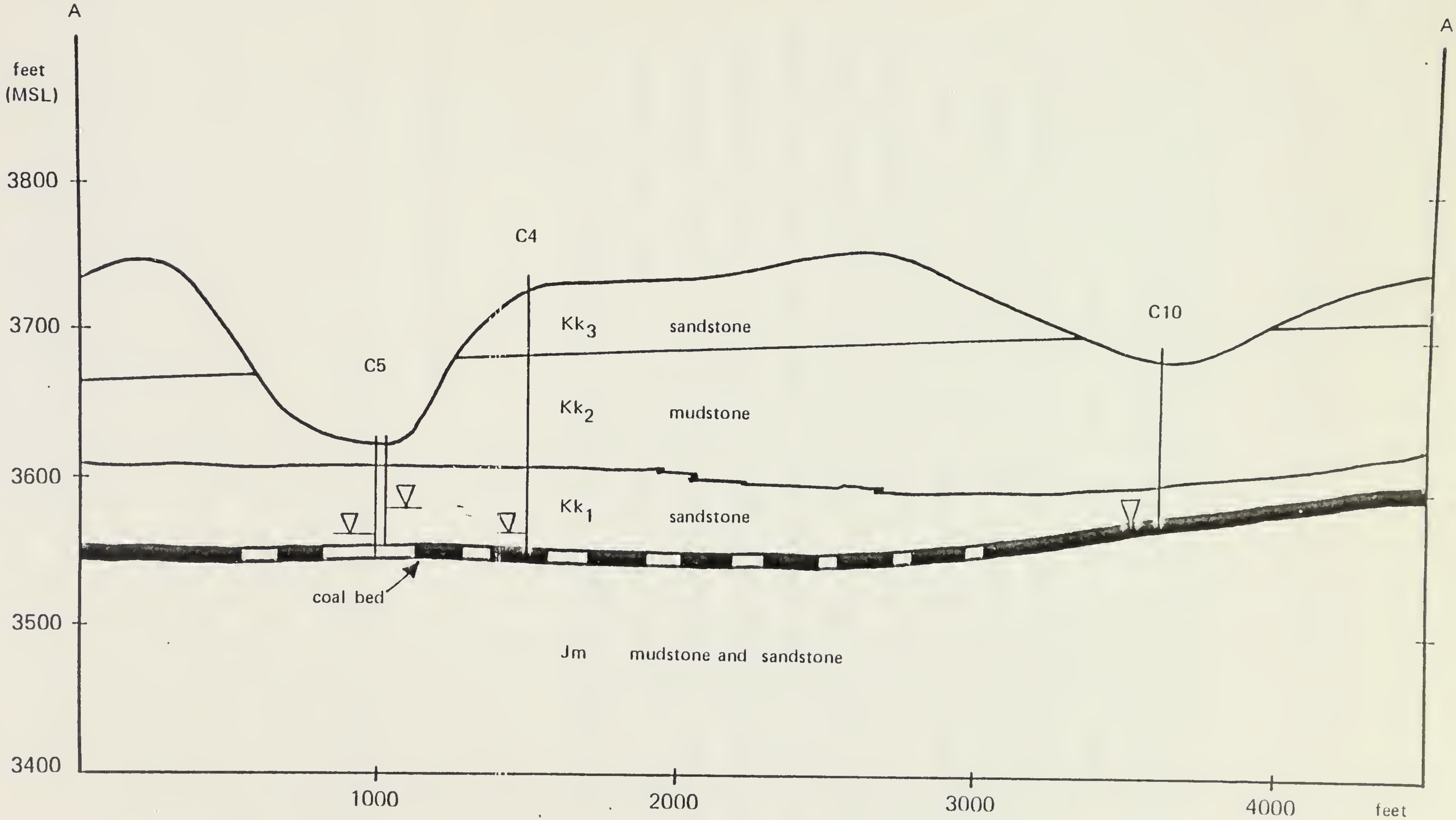


Fig. 7

Geologic cross section through the southwest side of the Upper Carbon Mine



Legend

C4, C5, C10 – wells

∇ – static water level

in coulees extend through confining units, thereby allowing inter-aquifer leakage. Leakage of mine water from the Upper Carbon Mine to the Madison aquifer is likely.

Local geologic structure exerts a major control on the mine-water chemistry of the Upper Carbon Mine. Contours of the top of the Morrison coal bed near Upper Carbon Mine are shown in Figure 8. Local folding of bedrock units produced a slight structural depression in the middle of the mine. This suggests that most of the mine is entirely flooded. At well C5-75, there was 12 feet of artesian head above the level of the mine roof.

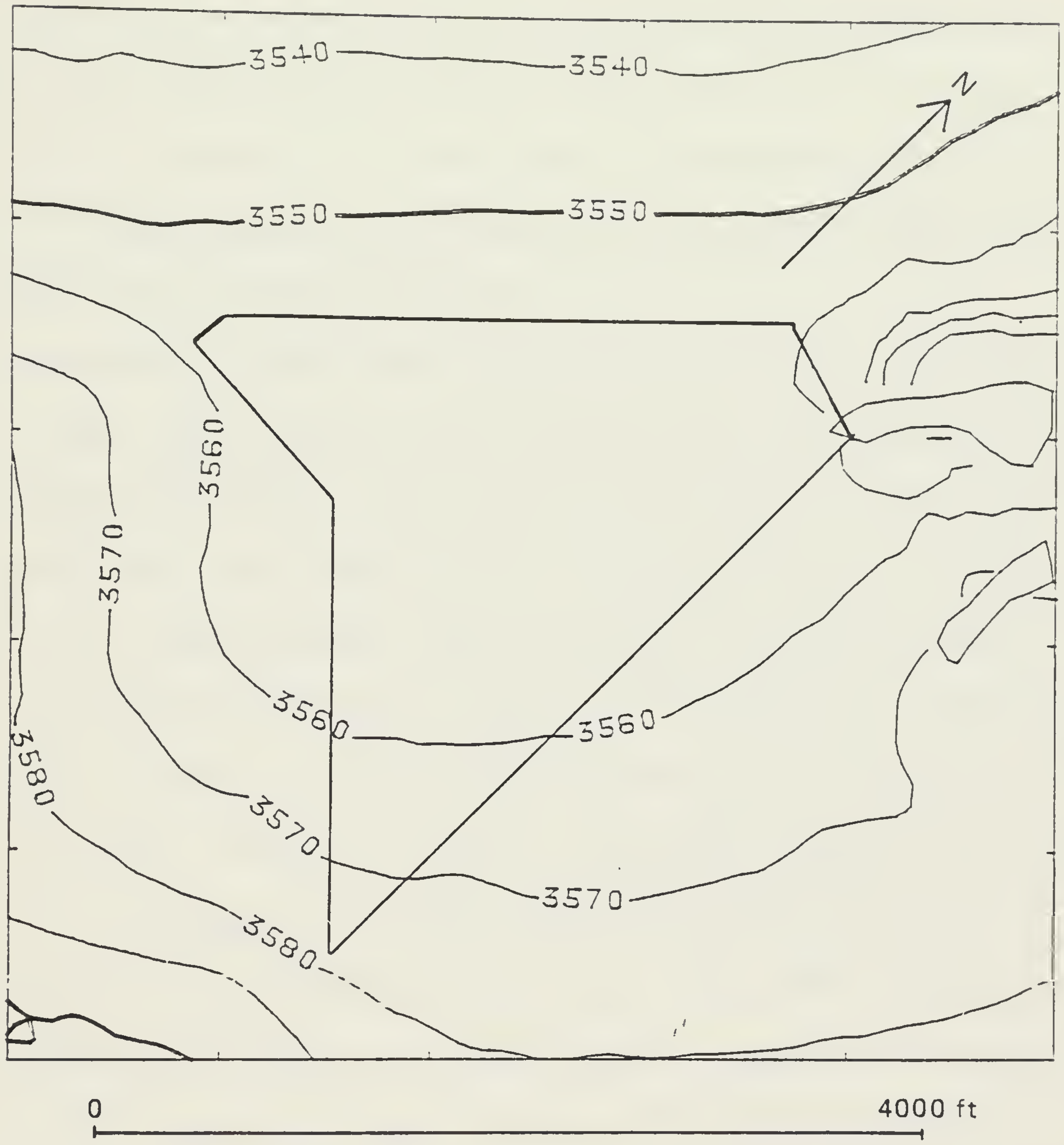
The mine discharge from the adit at AS01 is on the flank of a small anticline where the elevation of the mine roof is slightly higher than the water surface in the mine. This changes the mine environment from a flooded condition, generally devoid of oxygen, to a partially flooded situation in the last few hundred feet of the mine tunnel where atmospheric oxygen has access. The pH of the water in the mine drops from 6 at C5-75 to 2-3 at AS01, because of the availability of oxygen to bacterially mediated pyrite oxidation reactions.

Suggested hydrologic system controls

Because most of the mine, other than the entrance area, appears to be flooded, the mine conceivably could be bulkheaded with a seal to eliminate access of free air to the mine water; the seal could be constructed to allow mine water to be discharged. The water level at the mine portal would need to be raised approximately three feet. If successful, hydraulic sealing might reduce oxygen and bacterial populations to the extent that the discharge would stabilize at a pH in the range of 4 to 6, typical of

Fig. 8

Contours of the top of the Morrison coal bed, Upper Carbon Mine



Legend

Limits of the Upper Carbon Mine located in section 23, T.19 N., R. 5E.

3570 Isoline of the top of the Morrison coal bed, feet (MSL)

interior mine water. Potential problems include foundation engineering of the bulkhead in the unconsolidated rock materials filling the mine portal entrance, potential seepage of water and air through joints and fractures near the portal, and reduction of the currently high bacteria population in the mine. The latter problem could be addressed through the use of bactericides or surfactants at the time of bulkheading. Injection of apatite to create insoluable iron phosphate precipitates might also assist in breaking the acid production cycle.

Installation of slant wells in the artesian area of the basal Kootenai aquifer, which would discharge under siphon action, could reduce the leakage to the Upper Carbon Mine. This approach would depend on the success of a trial slant well. The potentiometric surface map (Figure 2) indicates that the mine first depressurizes, then underdrains a significant area of the basal Kootenai aquifer extending roughly 1 mile upgradient of the mine. There is a head loss of 100 feet within 2,500 feet of the southwestern boundary of the mine. Ideally, a system of horizontal drainage wells could be installed to discharge under siphon action, thereby reducing the hydraulic head available just upgradient of the mine. The overall feasibility and effectiveness of this technique would have to be evaluated following installation and testing of a pilot project. The pilot project has not been completed because of the inability to secure a driller who could install a slant well within the limitations foreseen.

Number Six Mine - CS09 (Takala site)

Characteristics

TABLE 4 below shows characteristics of mine discharge CS09 which drains the Number Six Mine.

TABLE 4 Characteristics of acid mine discharge CS09

Mine area	218 acres
Average discharge	0.097 ft^3/sec
Observed range	0.022 - 0.138 ft^3/sec
pH range	2.25 - 2.60
Specific conductance range	4865-7365 usiemens/cm

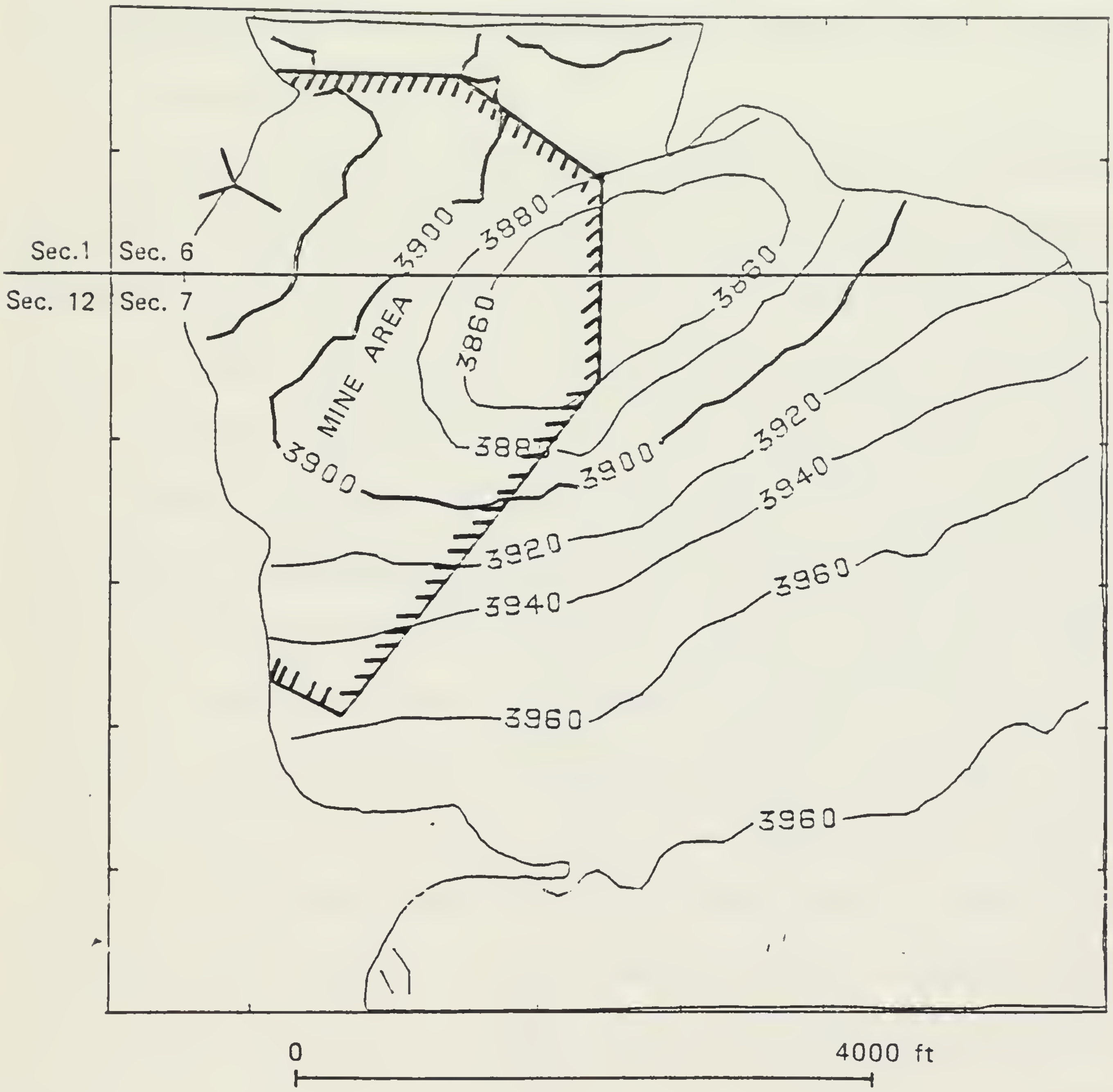
The Number Six Mine is characterized by a relatively constant discharge and a lack of sensitivity to specific recharge events. The lithology and thickness of the Kootenai units overlying the mine are substantially different at this site than at other mines.

The mine is constructed in an area of more pronounced geologic folding with over 100 feet of vertical amplitude in a distance of 5,000 feet as shown in Figure 9. At the mine portal, the basal Kootenai sandstone is 15 to 20 feet thick. However, it thins to the south and east and there are less than 3 feet of sandstone in drill holes T2-223 and T3-851. The sandstone in these holes was well cemented, and this unit is not an aquifer.

The Kk_3 quartzose sandstone is exposed at the land surface over the mine. It is somewhat thicker (50-85 feet) than at other mine sites and is

Contours of the top of the Morrison coal bed,

Number Six Mine, Stockett, Montana



Legend

Limits of the Number Six Mine located in sections 6 and 7, T.18 N. R. 5 E.

CS09 Acid mine discharge

3960 Isoline of the top of the Morrison Coal Bed, feet (MSL)

the only aquifer overlying the mine. It is separated from the mine by the thin Kk_1 basal sandstone unit and 80 to 100 feet of the Kk_2 mudstone unit. The source of water to the Number Six Mine is a slow, but steady, leakage from the Kk_3 sandstone through fractures and joints in the intervening 100 feet of mudstone, siltstone and sandstone. Figure 10 is a geologic cross section through the mine.

The local structural folding plays a major role in the hydrogeology of the mine. The structure is shown graphically in the three-dimensional diagram of Figure 11, which depicts the top of the Morrison coal bed and Figure 12, which shows the top of the Kk_2 mudstone unit (also the bottom of the Kk_3 quartzose sandstone aquifer). The surface topography also resembles the subsurface structure so that the discharge (CS09) from the mine and that of a natural fresh-water spring from the Kk_3 sandstone represent together most of the total groundwater discharge from the small topographic and structural basin. Note that the natural spring occurs at the point where the small coulee intersects the innermost point of the basin. There are several abandoned mine portals close to the one which is discharging (CS09). A survey of the mines and outcrop areas showed that the point of discharge is several feet lower in elevation than the others. Approximately one-half of the Number Six Mine is flooded. The mine becomes only partially flooded nearer the portal, and the access of atmospheric oxygen to the mine water promotes bacterially accellerated acid mine water production. The situation here is similar to the Upper Carbon Mine.

A map of the water-table elevation in the Kk_3 sandstone is shown in Figure 13. The water-table contours closely resemble the structure map and indicate that groundwater moves generally towards the spring which dis-

Fig. 10

Geologic cross section through the Number Six Mine, Stockett, Montana

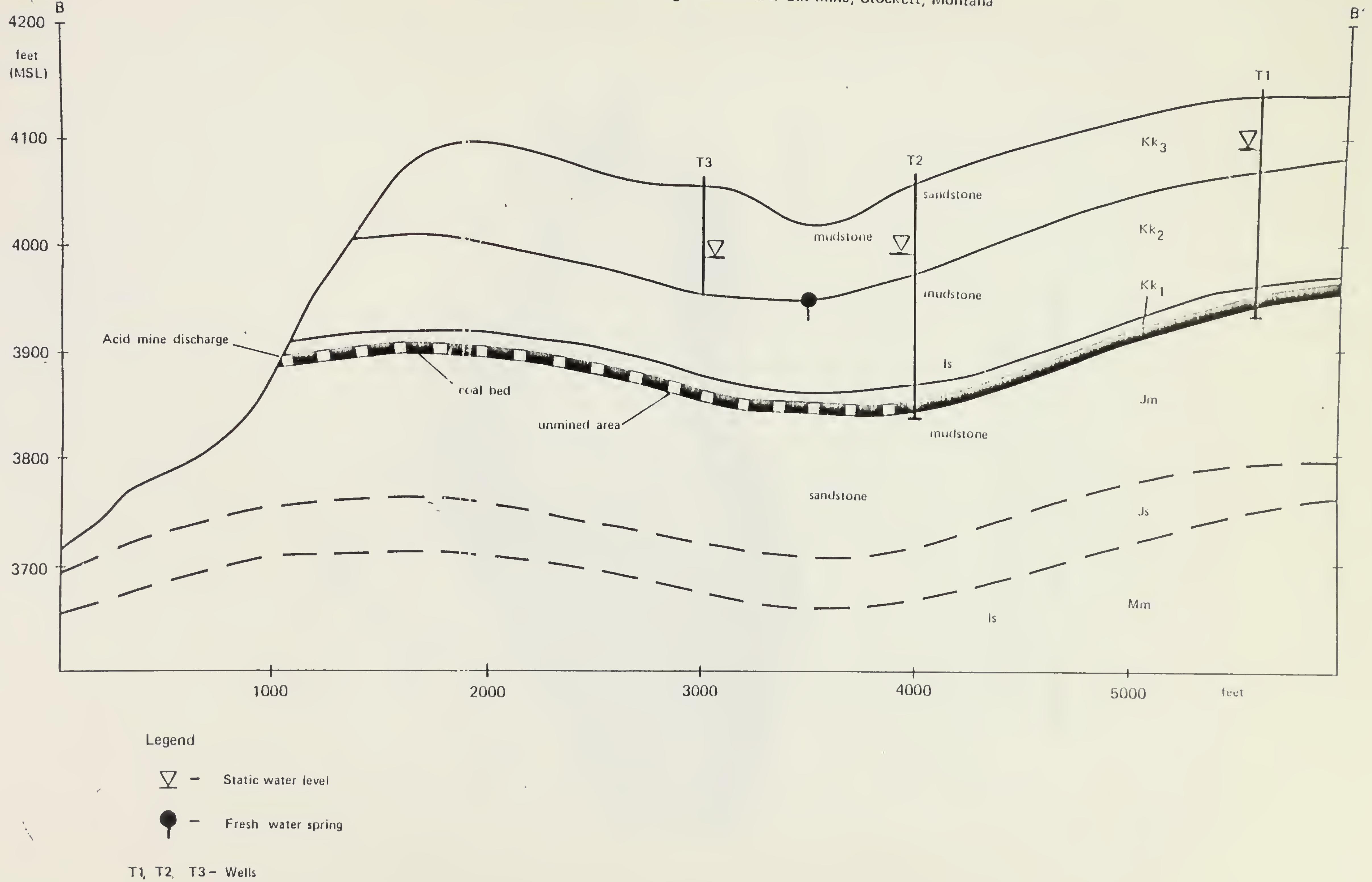


Fig. 11

Configuration of the top of the Morrison coal bed,

Number Six Mine area, Stockett, Montana

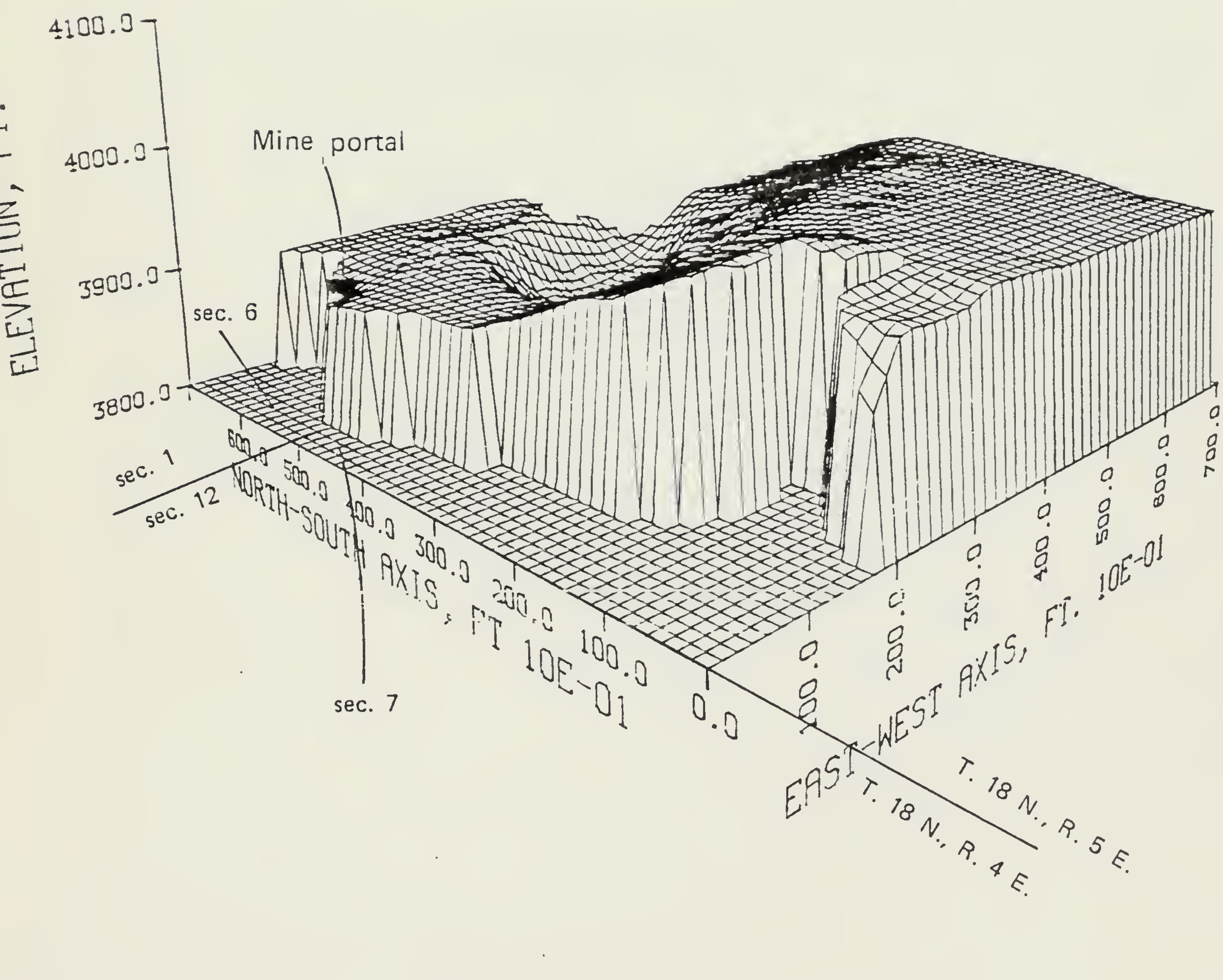


Fig. 12

Configuration of the top of Kk_2 mudstone unit,

Number Six Mine area, Stockett, Montana

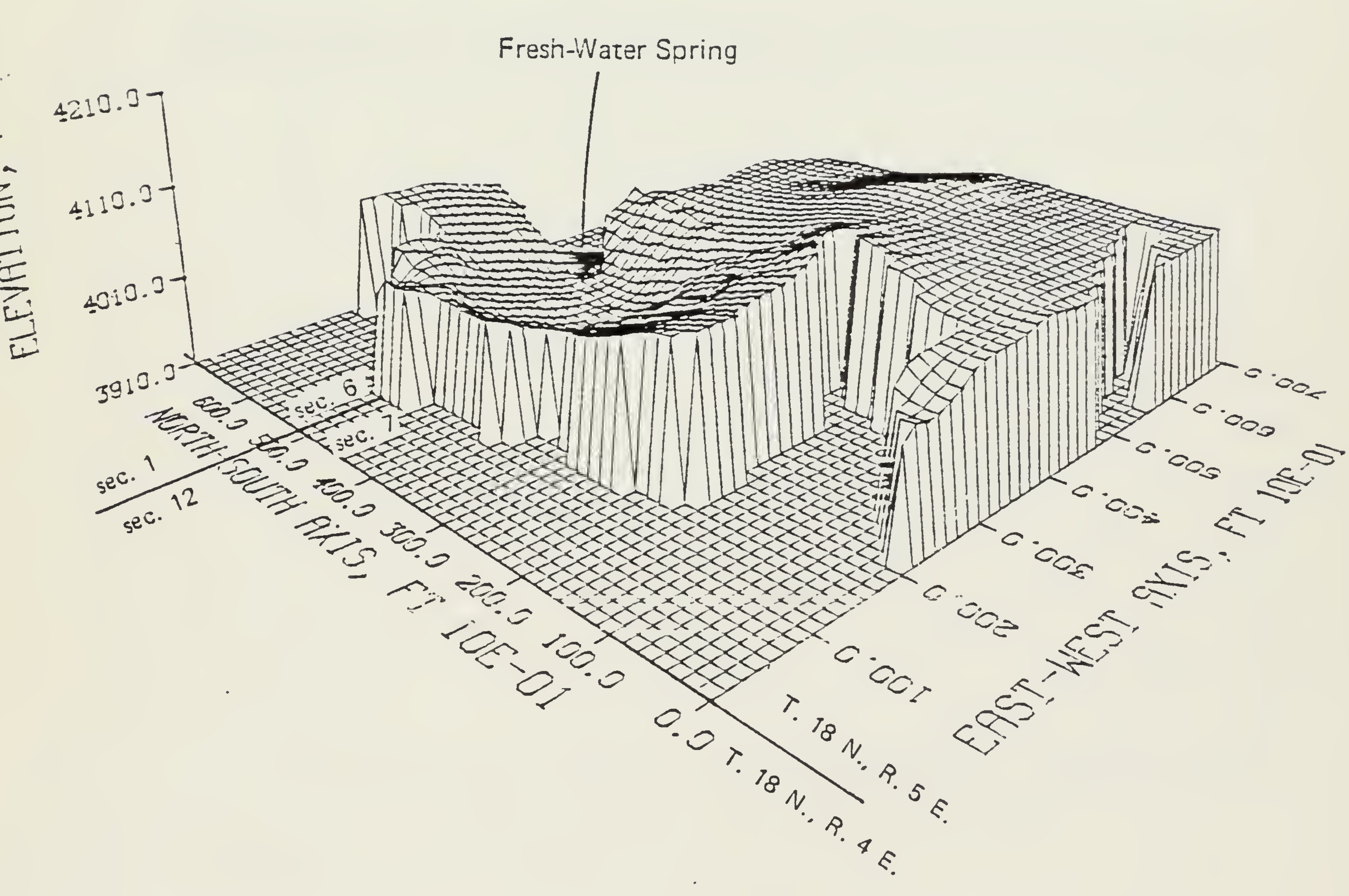
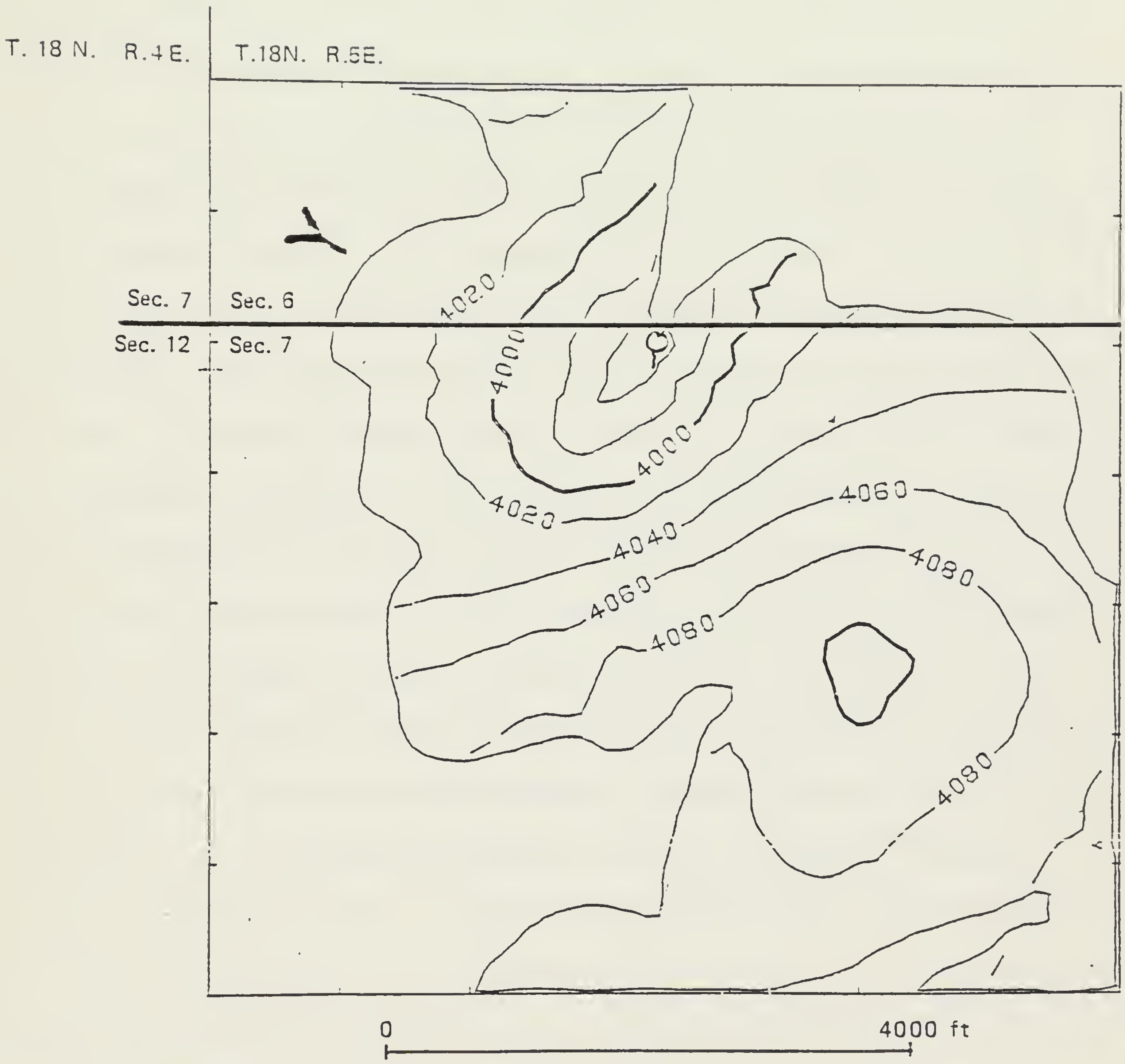


Fig. 13

Contours of the water table of the Kk_3 aquifer,

Number Six Mine area, Stockett, Montana



Legend

CS09 Acid mine discharge

4000 Isoline of the water table of the Kk_3 Aquifer, feet (MSL)

fresh-water spring

charges to the coulee in the northeast corner of the area. The contours are rather closely spaced, suggesting a fairly steep water-table gradient characteristic of low permeability rocks. A slug test on well T2-223 gave a horizontal hydraulic conductivity of 1.2×10^{-4} cm/sec, which is typical of unfractured fine-grained sandstone; this is considered low for productive aquifers. Groundwater recharged during major precipitation events would tend to cause an increase in storage, then would be dissipated gradually through spring discharge. This explanation is consistent with the observed behavior of the spring, which showed only long-term fluctuation within a narrow range. The spring discharges about 20 gpm from the pipe feeding the stock tank. Additional spring flow that could not be gaged was estimated to bring the total discharge to about 45 gpm. This is roughly equal to the average discharge of acid mine drainage from the mine portal.

The acid mine discharge (CS09) is similar in volume and in hydrologic response to the natural spring. Being 180 to 200 feet beneath the land surface of the bench and about 100 feet below the base of the Kk_3 aquifer, this mine is the deepest of those studied. Leakage of groundwater through fractures in the Kk_2 mudstone inevitably occurs, but specific recharge events are largely attenuated by the thick mudstone unit of low permeability. The discharge of the mine followed general precipitation patterns. Average annual discharge declined from 0.079 to 0.043 ft^3/sec between water years 1984 and 1985 because of the severe drought.

Suggested hydrologic system controls

The design of hydrologic system controls for the Number Six Mine is difficult because of the large separation of the mine from the surface and

the relatively large amount of groundwater in storage in the low permeability aquifer. Techniques which reduce recharge to the Kk_3 sandstone aquifer will tend to reduce acid mine discharge. The crop-fallow rotation on the bench overlying the mine undoubtedly contributes to surplus soil moisture and enhanced recharge to the mine. Approximately 110 acres are cultivated in small grains on the Takala property above the mine. Results of the intensified cropping practices on the Chartier site in 1984 indicated that there were two additional inches of recharge on the fallow field compared to the alfalfa or the land in grain. If alfalfa had been planted at Takala ranch, the recharge would have been reduced similarly. This reduction of recharge, if spread over two years (fallow crop cycle), would reduce equally the discharge of both the fresh-water spring and the acid mine discharge (CS09). If precipitation at two sites were the same, the reduction of discharge would be about 3 gpm or 10 percent of the present discharge of each. The Takala site, however, receives slightly more precipitation than the Chartier ranch, and alfalfa water consumption would be greater than in 1984. Therefore, the expected reduction of discharge would be about 20 percent.

One or more horizontal drainage wells could be expected to operate adequately in dewatering the Kk_3 aquifer and reducing leakage to the mine. The topography allows ready access to the mine from both the portal side (CS09) and northeast side. The most advantageous design may be to drill in a southwestward direction from a site near the natural fresh-water spring. The well axis would then be aligned with the axis of the structural syncline and take advantage of the maximum head potential. The well could be opened and closed to allow for stock-water supplies as required. Although the

discharge of the natural spring would probably decline, the total discharge from the well and spring would increase. The high-quality water could be stored in reservoirs further down the coulee. Potential water-rights problems would have to be worked out in advance. The well could be abandoned without any long-term impact, if necessary.

Old Anaconda Mine - CS07 (Johnson site)

Characteristics

General characteristics of the acid mine discharge CS01 are given in TABLE 5.

TABLE 5 Characteristics of acid-mine discharge, CS01

Mine area	190 acres
Average discharge	0.15 ft^3/sec
Observed range	1.18 - 0.007 ft^3/sec
pH range	2.28-2.88
Specific conductance range	1487-2103 usiemens/cm

The Old Anaconda Mine at Tracy is characterized by water containing only small amounts of iron and by a wide range of discharge sensitive to both precipitation events and dry weather. The lithologies of the Kk_2 mudstone and Kk_3 sandstone units are quite variable over the site and are different from the equivalent units at the two other study sites. There is a lack of distinct aquifers in these units and, instead, a set of variably saturated, thin sandstone and siltstone beds are present.

As at the other mine sites, local geologic structure plays a significant role in the groundwater and mine-water flow systems. Of the eight or more mine portals surrounding the Old Anaconda Mine portal, only one other (besides CS01) discharges any mine water, and then only on a very intermittent basis during large recharge events. A survey of the coal bed by the Montana Bureau of Mines and Geology revealed that the Old Anaconda Mine portal had the lowest elevation. The configuration of the top of the Morrison coal bed in the area of the mine is shown in Figure 14. Several small structural "highs" and "lows" are superimposed on the regional gradient. The main portion of the Old Anaconda Mine lies in a structural depression with groundwater discharge directed toward the portal by gravity drainage. Other portals are too high in elevation or are on the north side of drainages, cut off from the regional flow system.

A geologic cross section through the Old Anaconda Mine site is shown in Figure 15. The delineation of the Kk_1, Kk_2 and Kk_3 units is somewhat arbitrary because of the variable lithology of the Kootenai Formation in this area. The Kk_3 unit is dominated by mudstone and siltstone in most of the drill holes on the Johnson site. No continuous aquifer in the Kk_3 unit exists. Discontinuous, fine-grained sandstone beds are usually only partially saturated. They respond to recharge only during prolonged wet periods, but, apparently, soon drain through fractures downward to the mine. The wells at the J1 site near Gobbler Knob were the only Kk_3 wells to exhibit perennial saturation.

The Kk_1 basal Kootenai sandstone unit was found to be continuous in the mine area, varying from 24 to 60 feet thick. However, all of the wells completed in this unit indicated that the sandstone was only partially

Fig. 14

Configuration of the top of the Morrison coal bed.

Old Anaconda Mine area, Tracy, Montana

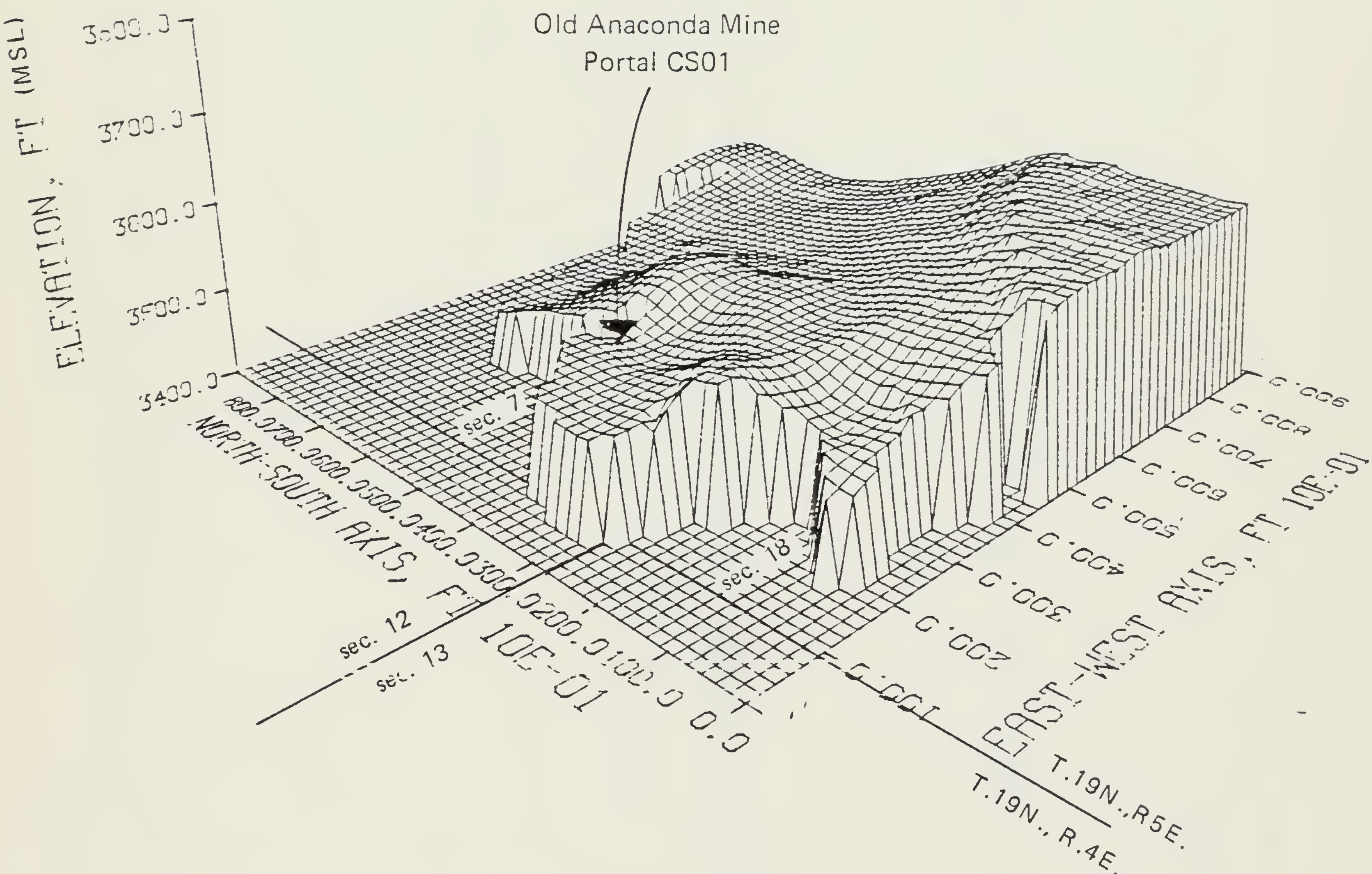


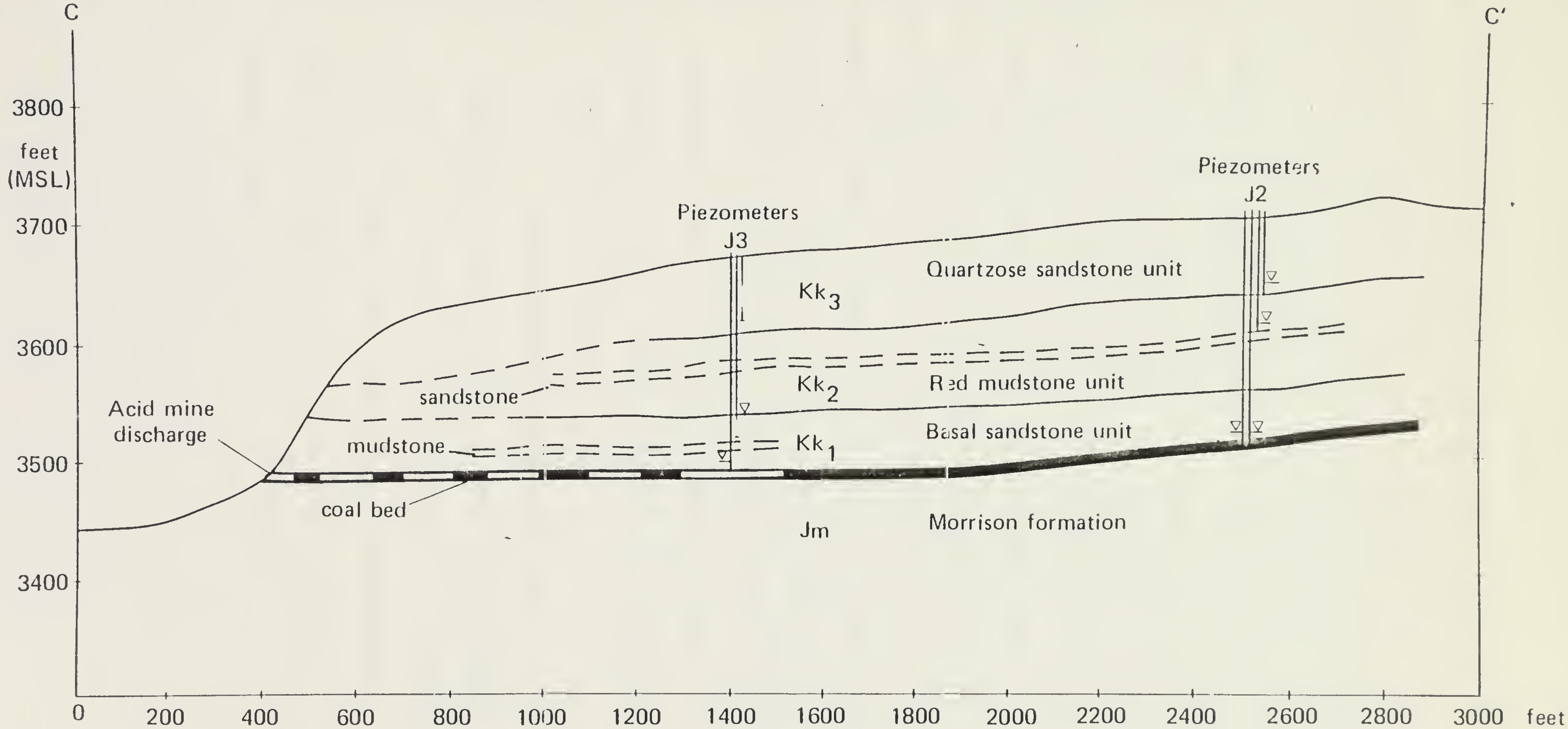
Fig. 1

Configuration of the top of the Flathead sand and

Old Anaconda Mine area, Philips, Montana

Fig. 15

Geologic cross section through the Old Anaconda Mine, Tracy, Montana



Legend

Kk – Kootenai Formation

Jm – Morrison Formation

∇ – Static ground–water levels

saturated; the saturation ranged from less than three feet in wells J2-210, J3-183 and J5-205 to about 7 feet in Well J4-197.

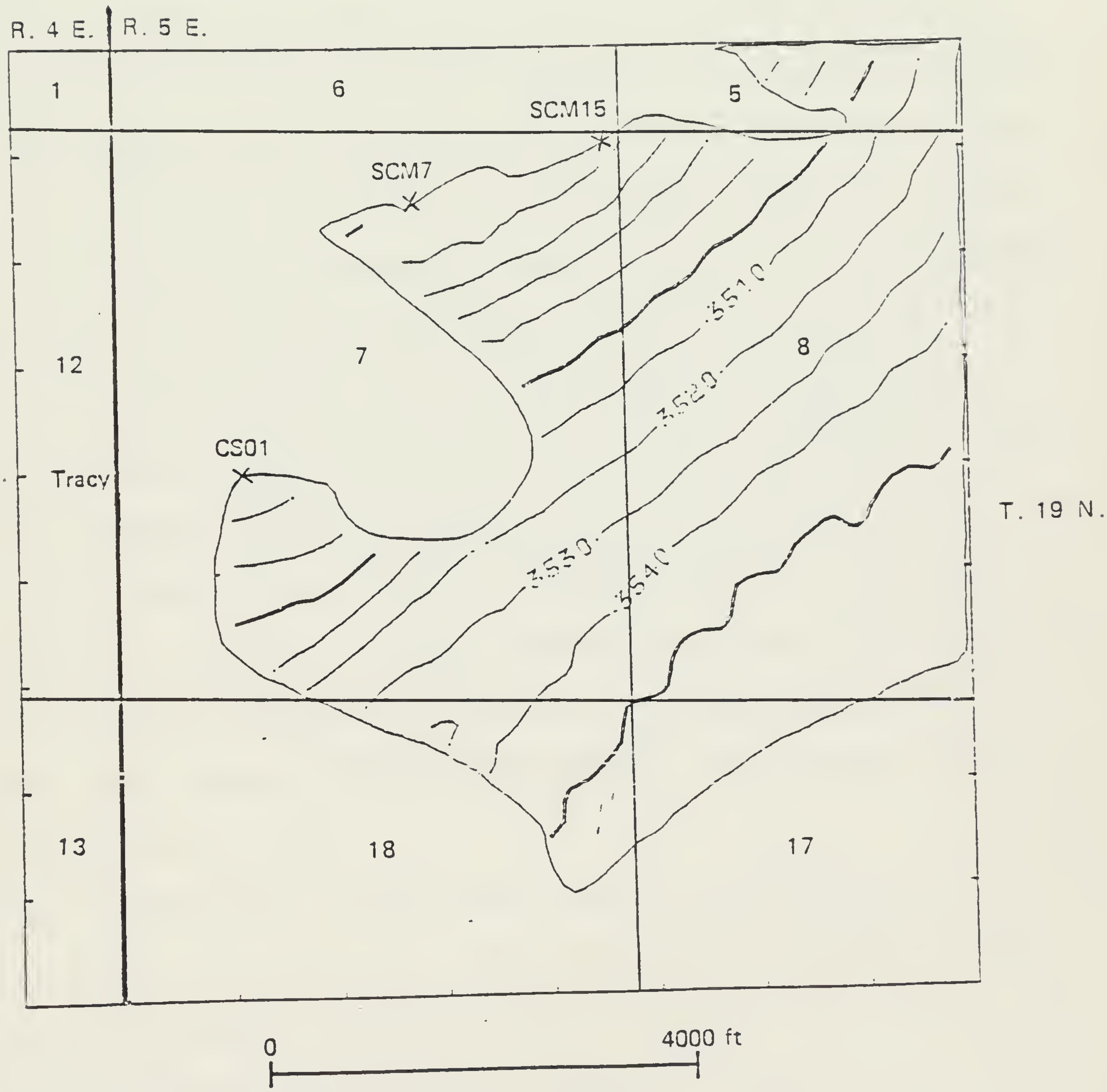
A remarkable feature of the Johnson site is the dramatic response of wells and the acid water discharge to heavy precipitation once the soils have been saturated. The acid discharge increased from 0.1 ft^3/sec to more than 1 ft^3/sec in less than 24 hours following heavy precipitation in early July of 1983. A dramatic increase in the water level in most piezometers was registered in the June to July, 1986, period following a return to more normal precipitation after the 1985 drought. The water level in well J3-183 rose 44 feet between June and July, 1986, and then fell 43 feet by August. A pervasive system of fractures is responsible for this type of response. On the bench just above the mine portal, several linear depressions, 1 to 3 feet deep and about 35 feet apart are evident. These are most likely related to subsidence in the mine. Subsidence-related fracturing and the natural fracture and joint system are coupled to create a rapid draining of the rock overlying the mine. This drainage is so effective that no permanent aquifers exist over or near the mine.

A map of water-table elevations in the Kk_1 basal sandstone is shown in Figure 16. Groundwater flow is generally from the southeast towards the northwest. In the lower part of the flow system, the saturated thickness is usually only one to three feet. The pocket in the system in the middle of the map, Figure 16, results to the unsaturated condition of the basal sandstone in the structurally high area at the head of Spring Coulee. The discharge of the mines near CS01 and that of the smaller mines on the north side of the bench (acid mine discharges SCM7 and SCM15--see Figure 16) probably account for the entire groundwater discharge from the Kootenai aquifers in the Gobbler Knob area.

Fig. 16

Contours of the water table of the Kk_1 basal sandstone,

Old Anaconda Mine area, Tracy, Montana



Legend

× Acid mine dishcarge

3540 Isoline of the water table of the Kk_1 unit, feet (MSL)

Suggested hydrologic system controls

The design of hydrologic system controls for the Johnson site mines was hampered by the lack of mine maps, particularly for the Old Anaconda Mine. The immediate response of the acid discharge to precipitation events also makes design difficult. Use of either cropping-system controls with alfalfa or horizontal drainage wells could mitigate the acid mine discharge to some degree. The pasture above the mine portal at present (1985) is too heavily grazed to be effective in evapotranspirational control. It is also doubtful that continuation of the flex-cropping method utilizing small grains will bring about observable results. Planting the bench area in the southern one-third of section 7 T. 19 N., R. 5 E. with a deep-rooted perennial could bring about long-term discharge reductions of at least 20 to 30 percent and lessen the frequency and intensity of peak mine discharges. The effectiveness of alfalfa in keeping the soil and sub-soil profiles at a low moisture condition will help considerably to create an unsaturated zone capable of storing more water, thereby allowing less recharge. This was well demonstrated at the Chartier site.

The use of horizontal drainage wells would be more problematic at the Johnson site than at the other two. Installation may be difficult because of extensive fracturing and subsidence above the portal. It is likely that a drainage well would produce little or no water for extended periods when hydraulic heads in the Kootenai aquifer are low, as in 1985. However, it is also likely that they would yield relatively large discharges during the brief, but intensive, recharge periods. In this capacity, they would considerably lessen the peak acid mine discharge.

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APPENDIX IA

1984 ANNUAL REPORT

STOCKETT-SAND COULEE

CROP WATER USE ESTIMATES

TRIANGLE CONSERVATION DISTRICT

STOCKETT SAND COULEE PROJECT: CROP-WATER USE AS A FACTOR OF GROUND WATER RECHARGE

Introduction

In May of 1984, a crop-water-use study was initiated at Ernie Chartier's (south of Sand Coulee) and Gene Johnson's (northeast of Tracy). The purpose of this study was to collect water-use data on intensive cropping systems that were implemented on two benchland areas above acid mine-water discharge sites. In addition, data collected in this study can be used to make some preliminary estimates of ground water recharge into the underlying coal mines.

It is postulated that the mines are recharged primarily by unused precipitation originating on the cultivated benchlands. In the past, these areas were farmed under an alternate crop/fallow farming system. The use of intensive vegetation management is a novel approach for acid mine drainage control. However, the concept of employing an intensive cropping system to prevent annual precipitation from entering shallow ground water aquifers is an accepted reclamation practice for saline seep.

In years of summer fallow, the amount of annual precipitation infiltrating the soil profile can exceed the amount of soil water that may be retained for crop use in the following year. As is the case in both acid mine drainage and saline seep, the infiltration of unused precipitation overloads the shallow ground water system which eventually leads to severe environmental hazards as the contaminated water resurfaces.

Methods

Both the Chartier and Johnson sites were selected by the Montana Bureau of Mines and Geology (MBMG) as the result of a preliminary investigation and inventory of acid mine drainage in the Stockett-Sand Coulee area (Open File Rpt. 109). The landowners involved were presented with this report and agreed to participate in the project.

In the spring of 1983, shallow ground water monitoring wells were drilled by the Triangle Conservation District (TCD) on the Chartier Ranch (T.14N., R.4E., Sec. 26). The purpose of the wells was to determine soil textures, depth to bedrock, and soil water conditions (see Appendix B). Later that spring and summer, MBMG began installing monitoring wells that penetrated the underlying bedrock zones. These deeper wells provided information on lithologies, stratigraphic relations and water bearing zones in the subsurface.

Base information on soil series have been developed by the United States Department of Agriculture - Soil Conservation Service and are published in the Cascade County Soil Survey. The soils were mapped primarily as two complexes. The first complex, Big Timber-Castner, consists of clay loam and channery loam soils. The second complex, Ipano-Ticell, consists of loam immediately underlain by sandstone. Due to the generalities of large scale mapping, such as with soil surveys, it was felt that information gathered from drilling and soil sampling was more specific to the site characteristics.

The soils information from the well logs of the shallow ground water monitoring wells was used to determine the average water holding capacity of the rooting depth profile. The calculations were based on estimates of water holding capacities with depth for individual textural horizons (Table 5, Appendix B). The overall water holding capacity for the site was based on weighted averages of the horizons within the well profiles.

Drilling indicated a consistent pattern of loam surface soils. The only exception is well No. 9, in the southeast corner of the alfalfa field (Appendix A), which has a clay loam surface texture. Subsequent horizons in the majority of the wells are either clay loam or clay ranging in thickness from one to four feet. These heavier textured soils immediately overlie fractured sandstone or shale. A corridor encompassing wells 1,3,4 & 5 has sandstone immediately underlying the loam soil profile, at an average depth of 51 inches. Well No. 6 deviates from

either pattern, in that it contains eight feet of gravelly loamy material immediately over sandstone.

There are approximately 646 acres contained within the Chartier's project site. Although the drilling data only covers the western 212 acre portion, soil sampling on the remaining 434 acres has indicated profile characteristics similar to the western site. The average total water holding capacity for the two sites has been calculated to be 4.20 inches for a four foot profile.

Twelve soil samples were collected and analyzed to determine the fertilizer needs for 212 acres of an alfalfa/grass mixture that was seeded on a primary recharge site. Samples were taken from 0 to 6 inches and tested for phosphorus (P_2O_5). There were no attempts made to determine any nitrogen needs as alfalfa, if properly innoculated, fixes its own nitrogen. Phosphorus, however, is essential for insuring good quality and high yields in forage production. The P_2O_5 recommendations were based on the "Phosphorus Build and Maintenance" program that is advocated by Montana State University Extension Specialists. This program compares residual P_2O_5 in the soil with annual crop removal rates and expected stand life to determine an appropriate fertilizer rate for the expected yield. The formulations for the "Phosphorus Build and Maintenance" program as well as soil test results are located in Appendix C.

A total of 140 pounds of actual P_2O_5 (275 pounds of bulk 11-51-0 grade fertilizer) was broadcast, then incorporated with "duckfoot" cultivator and rod weeder attachment. Grain drills were attached to the tool bar to provide for packing of the seedbed. During the last week of May and first week of June (1983), four pounds of pure live seed per acre (PLS) of Oahe Intermediate Wheatgrass was seeded with four pounds of PLS/acre of Ladak 65 alfalfa seeded at a 45° angle to the grass rows. Conventional grain drills were used with the seed tubes pulled out of the openers, allowing the seed to free fall onto the ground. The pracker wheels on the drills pressed the seed into the firmed seedbed. It was estimated from appearance that there was near to a 100% germination.

In May of 1984, an additional 316 acres of recharge area northeast and east of the alfalfa (T.19N., R.4E., Sec. 24 and 25) were seeded to small grains. Of this 316 acres, 260 acres were seeded to barley and 56 acres seeded to winter wheat. Approximately 70% of this acreage was flex-cropped with barley seeded into either barley or spring wheat stubble from the 1983 crop. Fertilizer recommendations for these small grain crops were based on soil testing performed in the Fall of 1983. In addition, 118 acres of this area were left in fallow during the

1984 growing season.

A flexible cropping system is based on stored soil moisture at the time of seeding plus the expected growing season precipitation based on a 70% probability of precipitation map (Appendix D). As as example, soils from the flexcrop area hold 2.2 inches of plant available water per foot of soil. If the soil profile is moist to a depth of two feet (based on use of the Paul Brown Moisture Probe), there would be a total of 4.4 inches of stored soil moisture. The expected growing season precipitation (5.5 inches) coupled with the total stored soil moisture equals 9.9 inches. This amount of moisture is sufficient to produce a good crop. The yield will then depend on the timeliness of the precipitation, weed control, adequate fertilizer application, etc.

An evaporation station was set up between the alfalfa/grass and flexcrop fields (Appendix A). The station is very simple consisting of a galvanized No. 1 or No. 2 wash tub, 20 inches in diameter and 10 inches deep (Figure 1). The tub

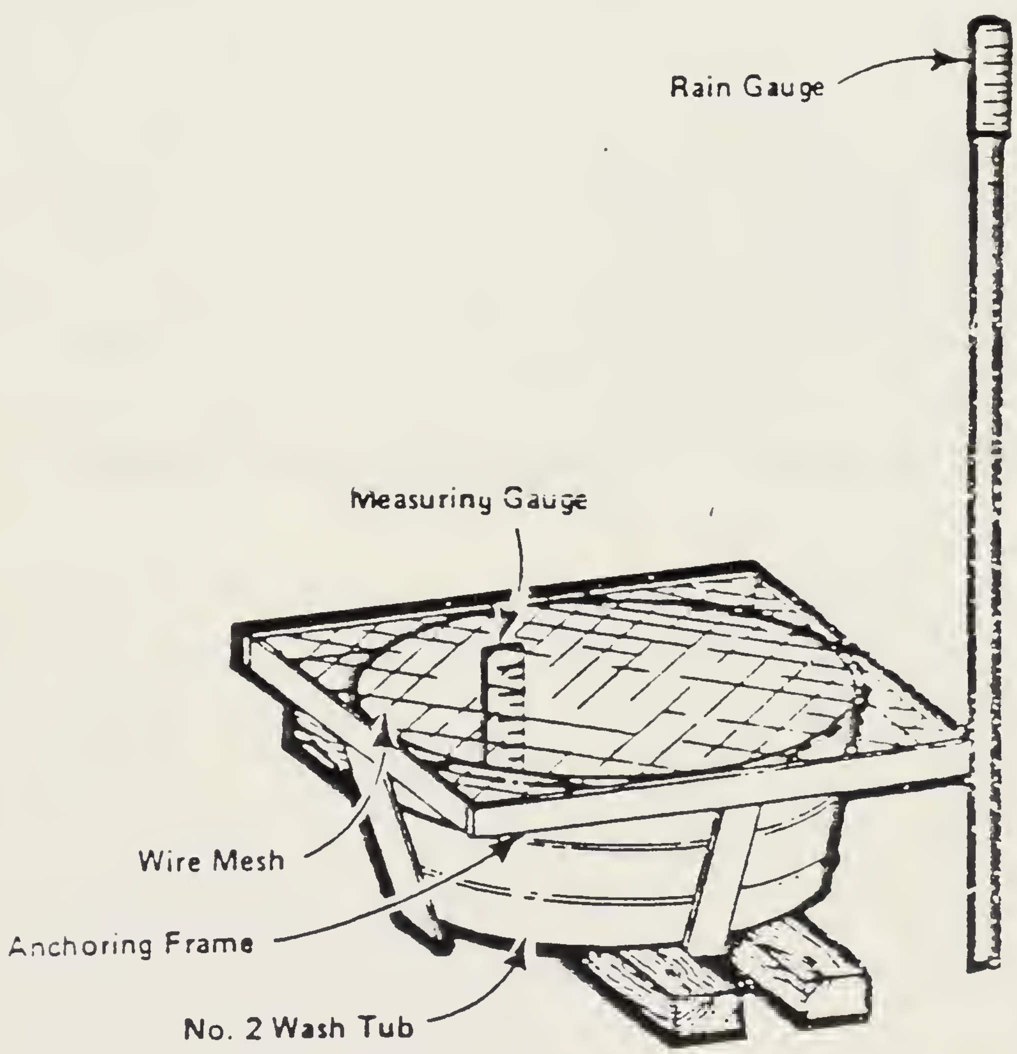


FIGURE 1

is placed on a framework of two x four inche blocks, leveled and staked down. One inch chicken wire is placed over the tub to prevent animals and birds from getting at the water. A plastic ruler is attached to the chicken wire so as to extend ver-

tically into the wash tub and resting on the tub's bottom. The ruler remains stationary so that all readings are consistent. Adjacent to the tub is a rain gauge fastened to lathe approximately three feet from the ground surface. The gauge was filled to 1/8 of an inch with water and an additional 3/8 of an inch of mineral oil. The oil prevents evaporation from the rain gauge. At the beginning of the crop water-use study, readings were taken only once a week. However, due to drought conditions with high winds that resulted in high evaporation rates, data collection frequency was increased to twice a week.

In conjunction with the evaporation pan data, the "Feel and Appearance" method for determining cumulative amounts of water remaining in the soil profile was used. This method entails sampling the soil profile at various depths with a hand probe and determining the moisture content of the soil profile by comparing soils condition with that expressed in Table One. The combination of both evaporation pan data and the "Feel and Appearance" method provide a relatively reliable estimate of potential plant water use (potential evapotranspiration - PET). In addition, they are practical methods for determining crop water-use without involving expensive monitoring devices.

Monitoring wells were also drilled on Gene Johnson's site (T.19N., R.5E., Sec. 7 and 8). Appendix A shows the locations of the monitoring wells, as well as the location of the evaporation station on Gene Johnson's land. Roughly 875 acres were to be intensively farmed within the guidelines of a flexible cropping system. During the past growing season (1984) 400 acres were seeded to winter wheat, 350 acres to spring wheat and 125 acres to barley, all of which was summer fallowed in 1983.

The dominant soil on the Johnson site is the Darret-Castner complex consisting of silty clay loam and channery sandy loam soils (based on the Cascade County Soil Survey). Drilling information has indicated that the well profiles coincide with the soil survey series identified for the site. The only variance from the soil series type section is in depth to bedrock being deeper on the Johnson site (Appendix B). The water holding capacity was calculated in accordance with the method described on the Chartier site. The water holding capacity for the Johnson site is 5.77 inches for a four foot profile.

Results

Table Two lists the average daily and average weekly crop water use rates in weekly increments for the alfalfa, barley, spring wheat and winter wheat. This information was generated from the evaporation pan data. Table Three also lists

Table 1. Approximate remaining depletable moisture in the soil based on texture, feel and previous history.

% of AWC remaining in soil	Feel or appearance of soil			
	Coarse-textured soils	Moderately coarse textured soils	Medium-textured soils	Fine and very fine textured soils
0 percent	Dry, loose, and single-grained; flows through fingers.	Dry and loose; flows through fingers.	Powdery dry; in some places slightly crusted but breaks down easily into powder.	Hard, baked, and cracked; has loose crumbs on surface in some places.
50 percent or less.	Appears to be dry; does not form a ball under pressure.[1]	Appears to be dry; does not form a ball under pressure.[1]	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls under pressure.[1]
50 to 75 percent.	Appears to be dry; does not form a ball under pressure.[1]	Balls under pressure but seldom holds together.	Forms a ball under pressure; somewhat plastic; sticks slightly under pressure.	Forms a ball; ribbons out between thumb and fore-fingers.
75 percent to field capacity.	Sticks together slightly; may form a very weak ball under pressure.	Forms weak ball that breaks easily; does not stick.	Forms ball; very pliable sticks readily if relatively high in clay.	Ribbons out between fingers easily; has a stick feeling.
At field capacity (100 percent).	On squeezing, no free water appears on soil but wet outline of ball is left on hand.	Same as for coarse-textured soils at field capacity.	Same as for coarse-textured soils at field capacity.	Same as for coarse-textured soils at field capacity.
Above field capacity	Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles; free water forms on surface.

[1] Ball is formed by squeezing a handfull of soil very firmly.

water use rates, however, they are based on the "Feel and Appearance" method. The field sheets used in calculating these values are enclosed in Appendix E. Figures two thru nine are graphs of the average daily water use for the four different crops based on evaporation pan data (Figures 2 thru 5) and the "Feel and Appearance" method (Figures 6 thru 9). Precipitation amounts for these weeks are also graphed.

The differences between data from the evaporation pan and from the "Feel and Appearance" are due to the limitations of each method. The evaporation pan method shows the amount of water plants could potentially use, providing that soil moisture is not a limiting factor. When soil moisture is high, values from the evaporation pan method and the "Feel and Appearance" method are very similar and closely approximate actual consumptive crop water-use. As soil moisture contents drop below 75% of field capacity, the evaporation pan method tends to overestimate crop water use rates. Penman (1949) attributes the divergence of actual evapotranspiration and potential evapotranspiration to the root constant. This root constant takes into account the amount of water readily available within the roots range and is a function of increased adhesive, cohesive and osmotic forces in the soil profile as soil moisture conditions approach the wilting point.

The "Feel and Appearance" method, in conjunction with a precipitation gauge, estimates the amount of precipitation in excess of the soils moisture storage capacity. It does not, however, indicate how much water was used by the crops versus how much water leached downward as the result of precipitation events. This is where the evaporation pan method supplements the "Feel and Appearance" method.

The evaporation pan estimates for the growing season indicate cumulative crop water use values for the Chartier alfalfa and barley and Johnson barley, winter wheat and spring wheat at 11.62, 13.16, 15.59, 11.20 and 15.59 inches, respectively. However, the total maximum water holding capacities for the soil profiles are 4.20 inches (Chartier site) and 5.77 inches (Johnson site). In addition, the total precipitation for the growing season for the two sites was only 4.94 and 3.96 inches, respectively. Consequently, the total available water for each site could have only been 9.14 and 9.73 inches. In comparison, the "Feel and Appearance" method appears to be more accurate. Cumulative crop water use rates over the growing season for the same crops were: 5.18, 5.60, 6.86, 6.65 and 6.86 inches, respectively. The stored soil moisture plus the effective rainfall for the two sites was 7.77 and 8.40 inches.

Table 2: Water Use Rates In Inches Based On Evaporation Pan and Rainfall On A Weekly Basis.

	Chartier Site				Johnson Site			
	Alfalfa		Barley		Winter Wheat		Spring Grains	
Week	daily	weekly	daily	weekly	daily	weekly	daily	weekly
5/13 - 5/19	.16	1.12	.09	.63	.19	1.33	.04	.12
5/20 - 5/26	.15	1.05	.11	.77	.15	1.05	.06	.42
5/27 - 6/2	.20	1.40	.15	1.05	.21	1.47	.15	1.05
6/3 - 6/9	.09	.63	.07	.49	.08	.56	.07	.49
6/10 - 6/16	.11	.77	.10	.70	.13	.91	.11	.77
6/17 - 6/23	.13	.91	.13	.91	.18	1.26	.17	1.19
6/24 - 6/30	.17	1.19	.29	2.03	.29	2.03	.30	2.10
7/1 - 7/7	.10	.70	.14	.98	.22	1.54	.26	1.82
7/8 - 7/14	.16	1.12	.21	1.47	.15	1.05	.27	1.89
7/15 - 7/21	.16	1.12	.20	1.40			.26	1.82
7/22 - 7/28	.23	1.61	.19	1.33			.22	1.54
7/29 - 8/4							.16	1.12
8/5 - 8/11							.18	1.26
Total	1.66	11.62	1.86	13.16	1.60	11.20	2.25	15.59
Average	.145	1.056	.155	1.097	.178	1.244	.173	1.199

Table 3: Water Use Rates In Inches Based On Feel and Appearance Method Plus Effective Rainfall On A Weekly Basis

	Chartier Site				Johnson Site			
	Alfalfa		Barley		Winter Wheat		Spring Grains	
Week	daily	weekly	daily	weekly	daily	weekly	daily	weekly
5/13 - 5/19	.09	.63	.09	.63	.13	.91	.08	.56
5/20 - 5/26	.03	.21	.02	.14	.05	.35	.05	.35
5/27 - 6/2	.11	.77	.05	.35	.16	1.12	.04	.28
6/3 - 6/9	0	0	.07	.49	0	0	.07	.49
6/10 - 6/16	.09	.63	.09	.63	.11	.77	.13	.91
6/17 - 6/23	.13	.91	.14	.98	.14	.98	.11	.77
6/24 - 6/30	.05	.35	.07	.49	.07	.49	.07	.49
7/1 - 7/7	.13	.91	.13	.91	.19	1.33	.11	.77
7/8 - 7/14	.05	.35	.05	.35	.06	.42	.13	.91
7/15 - 7/21	.02	.14	.02	.14	.04	.28	.07	.49
7/22 - 7/28	.04	.28	.03	.21			.07	.49
7/29 - 8/4			.04	.28			.02	.14
8/5 - 8/11							.02	.21
Total	.74	5.18	.76	5.60	.95	6.65	.98	6.86
Average	.067	.471	.063	.467	.095	.665	.075	.528

FIGURE 2: Average Daily Crop Water Use per Week for Alfalfa/Intermediate Wheatgrass Mixture and Rainfall Measurements, Chartier Site. Based on Evaporation Pan Method.

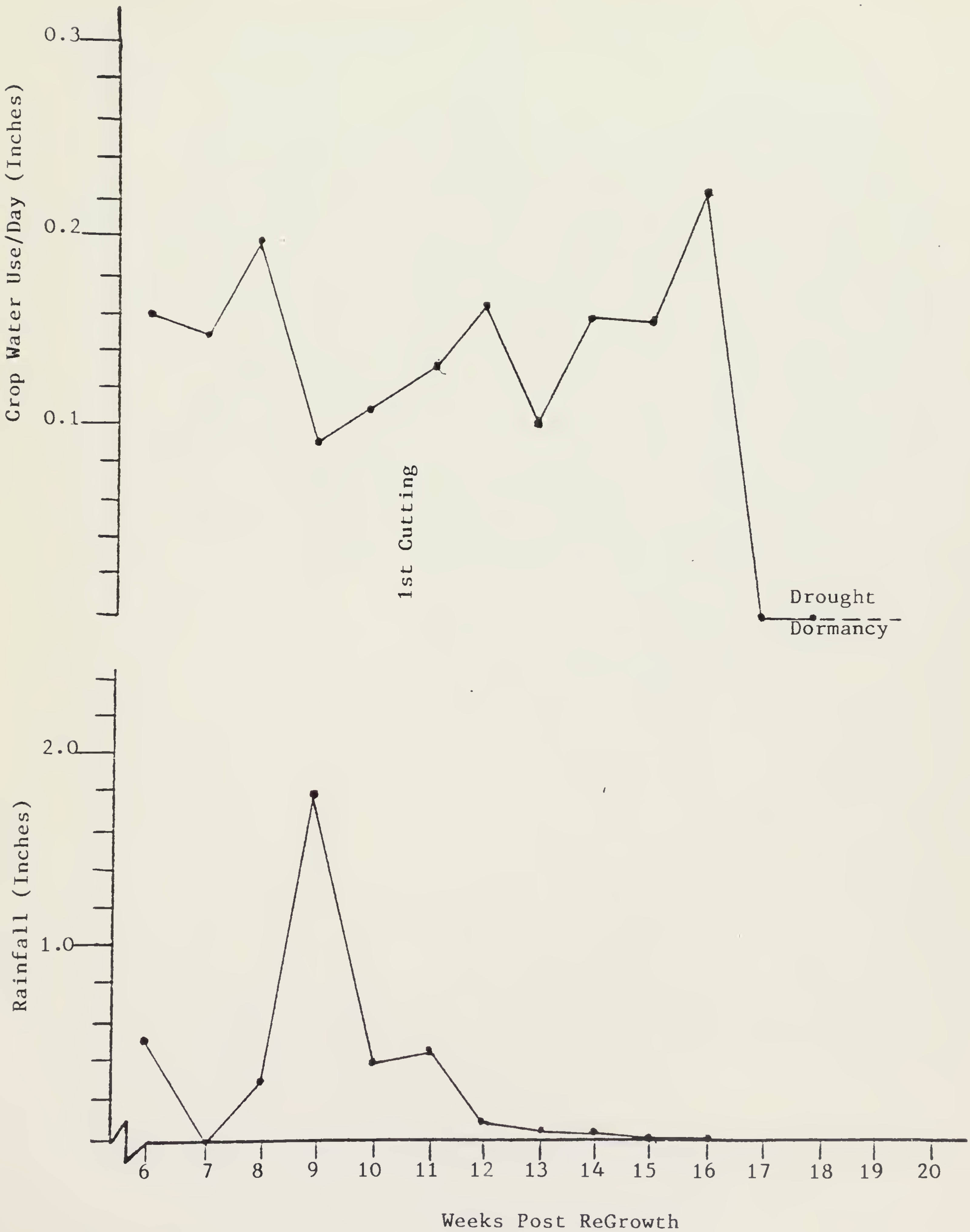


FIGURE 3: Average Daily Crop Water Use per Week for Barley and Rainfall Measurements, Chartier Site. Based on Evaporation Pan Method.

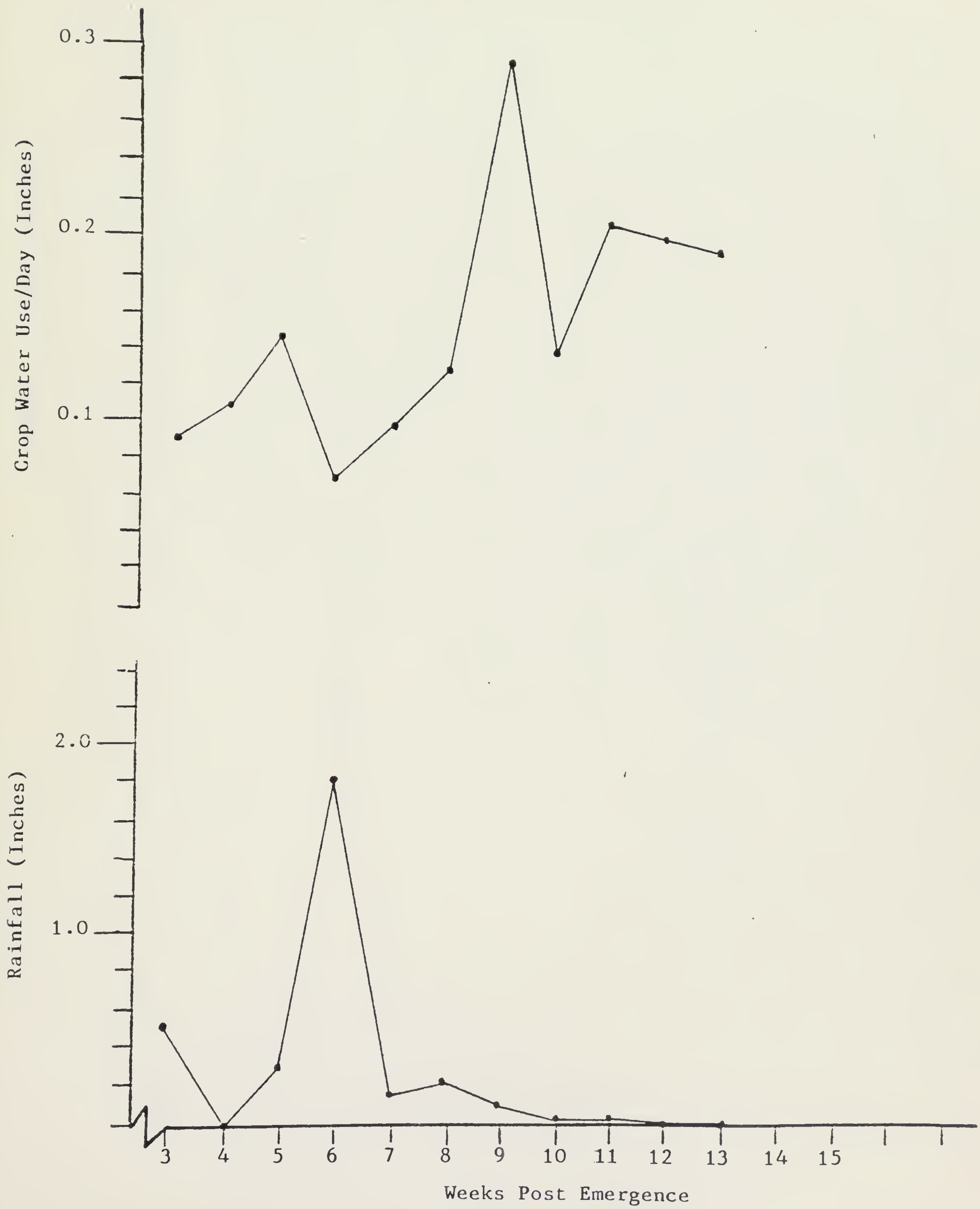


FIGURE 4: Average Daily Crop Water Use per Week for Winter Wheat and Rainfall Measurements, Johnson Site. Based on Evaporation Pan Method.

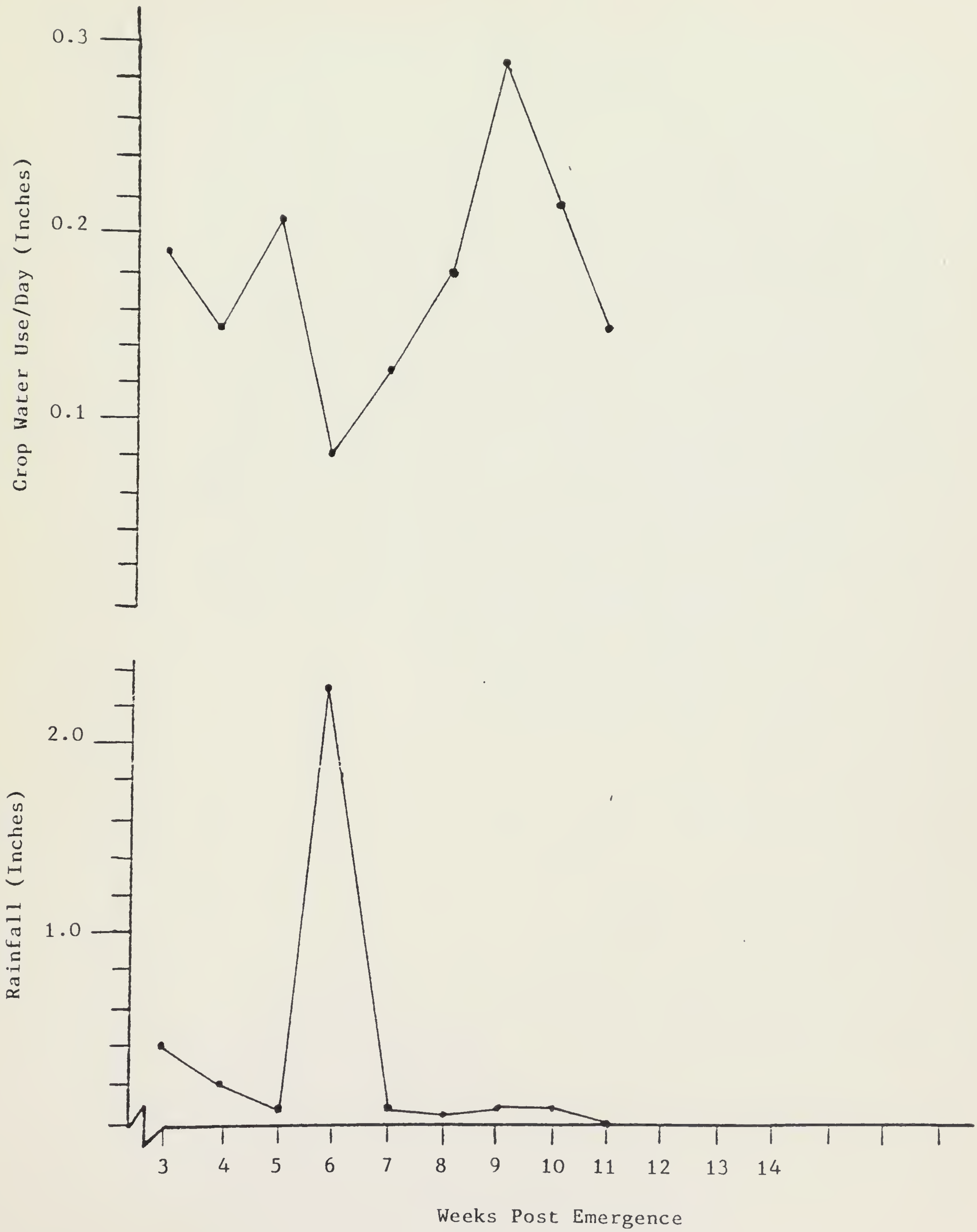


FIGURE 5: Average Daily Crop Water Use per Week for Spring Wheat and Barley and Rainfall Measurements, Johnson Site. Based on Evaporation Pan Method.

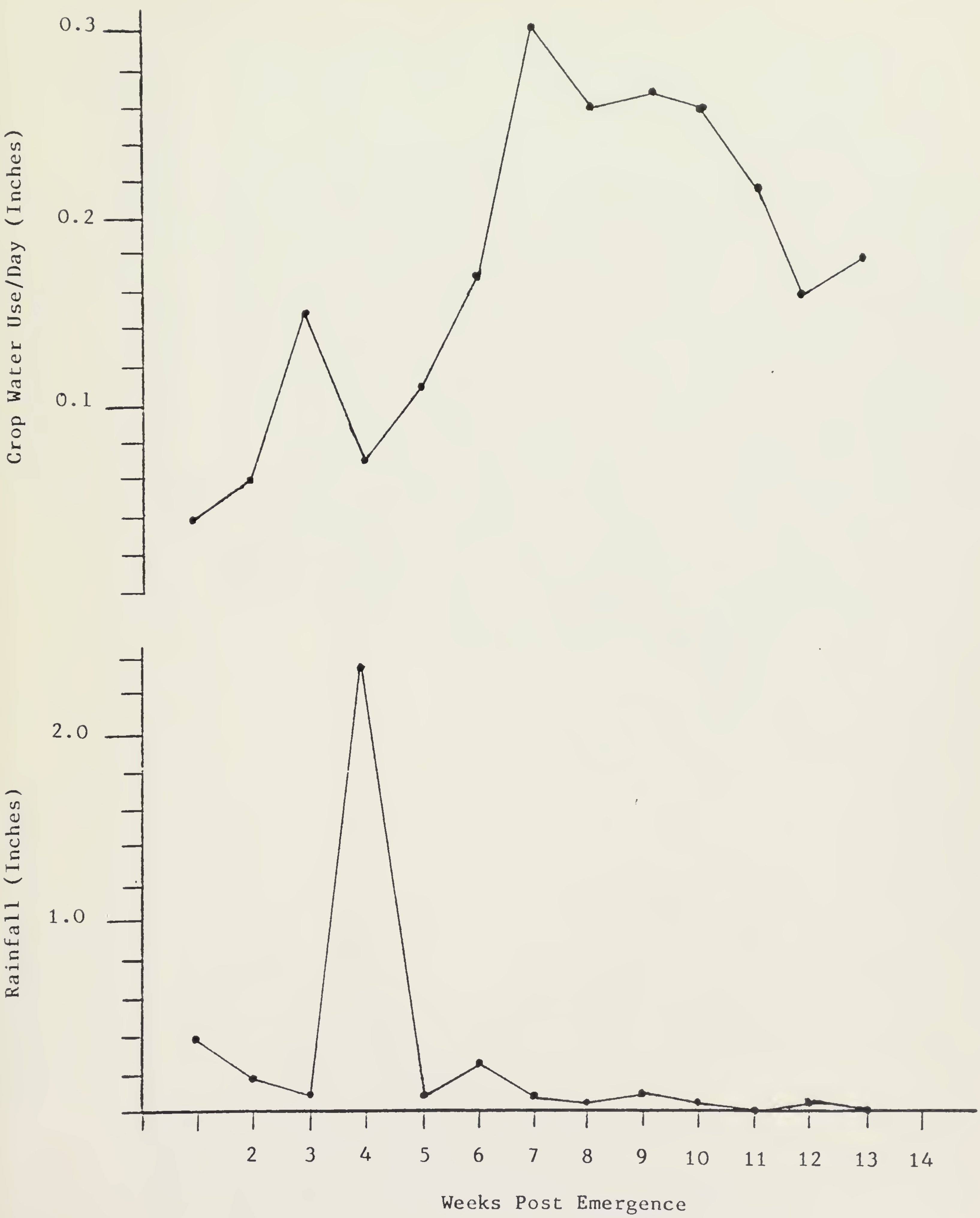


FIGURE 6: Average Daily Crop Water Use per Week for Alfalfa/Intermediate Wheatgrass Mixture and Effective Rainfall Measurements, Chartier Site. Based on Feel and Appearance Method.

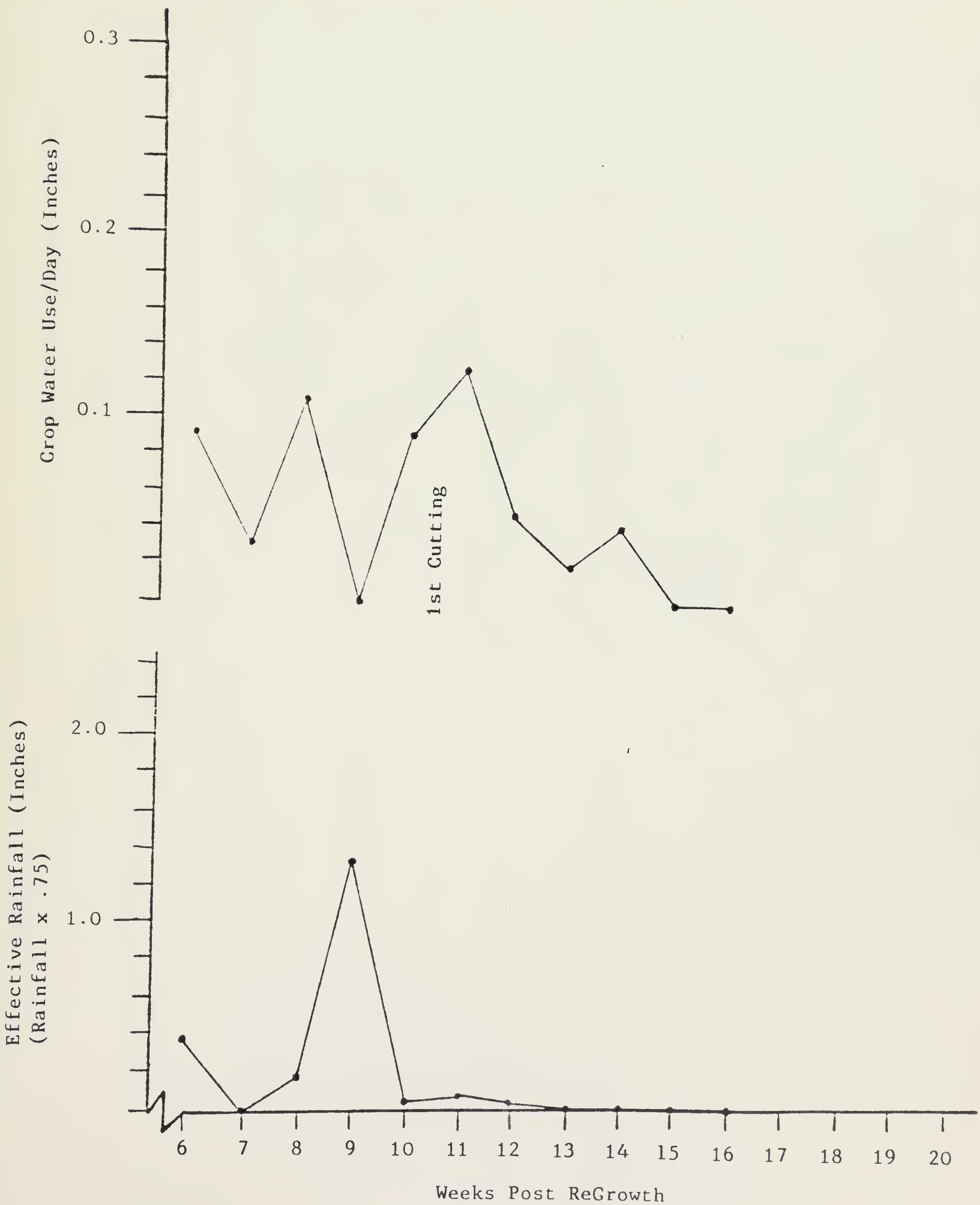


FIGURE 7: Average Daily Crop Water Use per Week for Barley and Effective Rainfall, Chartier Site. Based on Feel and Appearance Method.

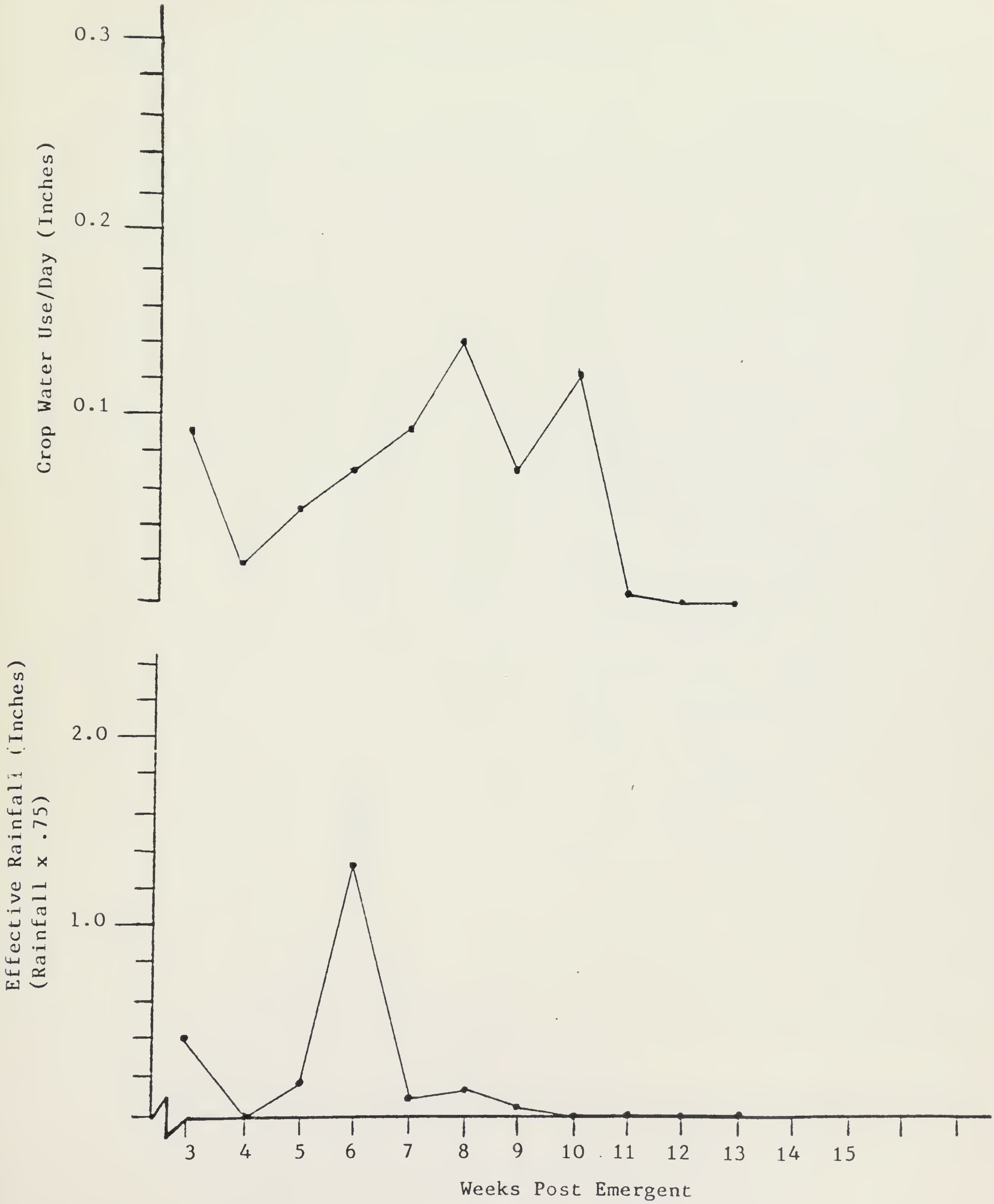


FIGURE 8: Average Daily Crop Water Use per Week for Winter Wheat and Effective Rainfall, Johnson Site. Based on Feel and Appearance Method.

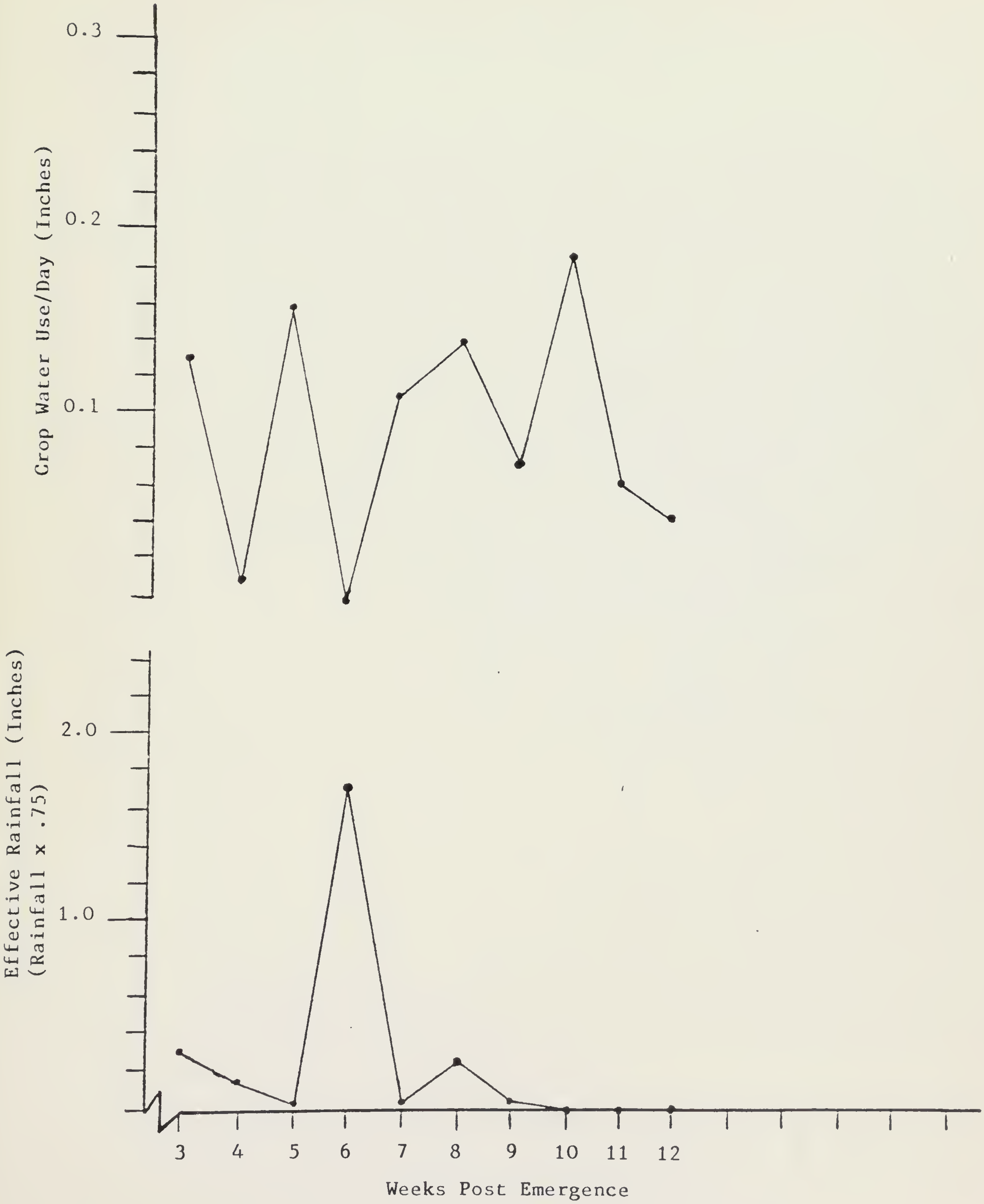
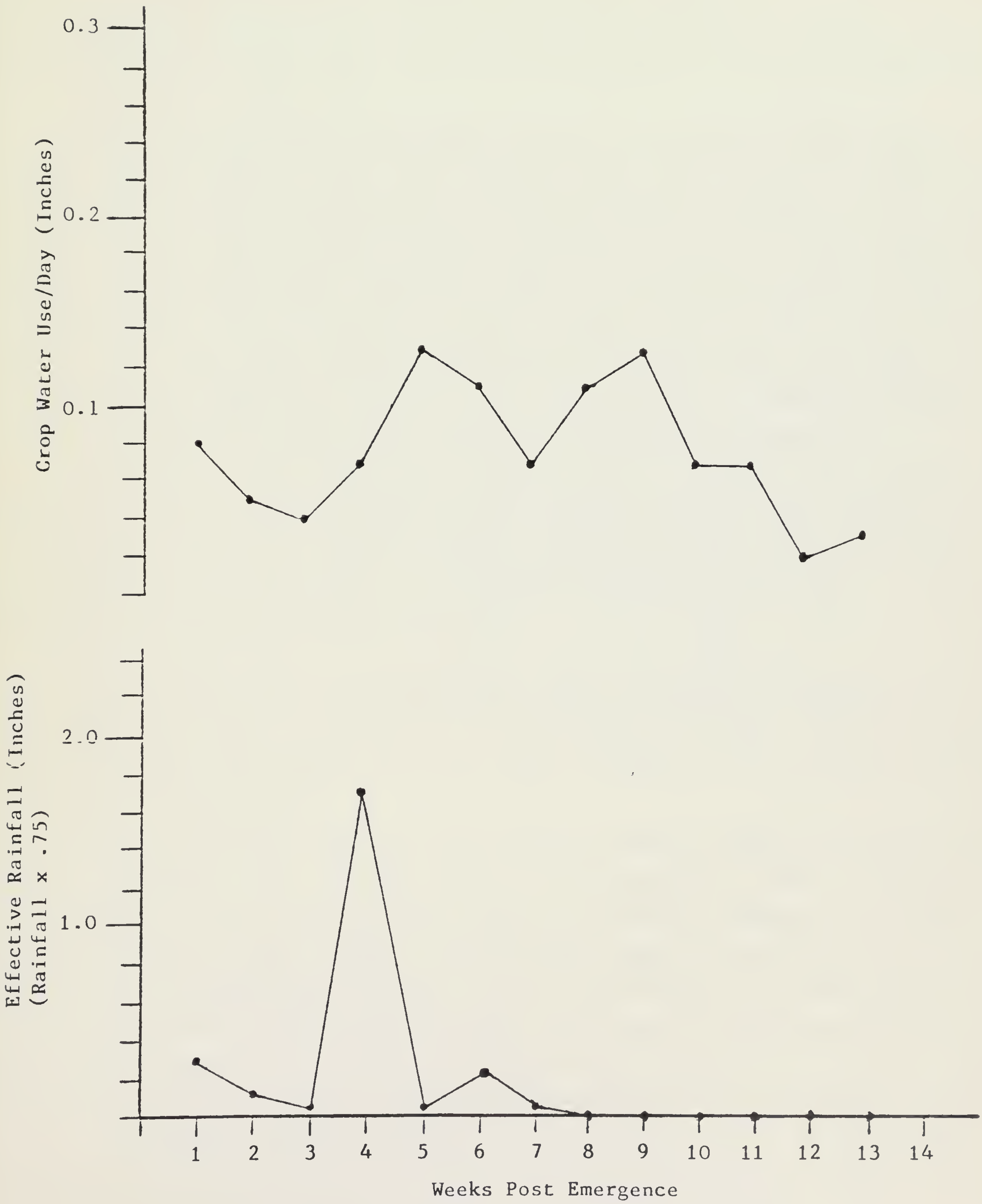


FIGURE 9: Average Daily Crop Water Use per Week for Spring Wheat and Barley and Effective Rainfall, Johnson Site. Based on Feel and Appearance Method.



Contrary to the evaporation pan estimates, the feel and appearance values are less than the total moisture that was available. As mentioned above, when moisture becomes the limiting factor, then the evaporation pan method tends to over estimate crop water use. The evaporation pan data can be thought of as the "potential" water use, where as the "Feel and Appearance" method can be thought of as the "actual" water use.

As would be expected, the graphs indicate a decrease in water use for all crops during or shortly after main precipitation events. This is primarily due to the cooler ambient temperatures and higher relative humidity. In some cases, crop water use rates are high even with adequate precipitation. One valid explanation is the growth stage in which the plant is in. Heading, anthesis (flowering) and early milk are very crucial periods in small grains. Water use is usually quite high during these stages. Different crop coefficient factors need to be considered when computing crop water use rates (Appendix F). They are simply the ratio of actual plant water use to potential or maximum crop water use.

In addition to estimating crop water use rates, a summer fallow field at the Chartier site was also monitored for soil moisture content. This check provides information on how much water is stored by the soil profile as well as loss due to evaporation or deep percolation. The "Feel and Appearance" method was used to determine the percent of field capacity.

Table 4 lists the estimated percent of field capacity on a weekly basis for the period of August 6 to November 25, 1984 (monitoring was initiated late due to an oversight - the importance of the summer fallow data did not become apparent until late in the season).

Research indicates that for every time an acre of land is tilled with a shovel cultivator, up to one half inch of soil moisture is lost to evaporation. This process is not a simple linear function but depends largely on the depth of and precipitation events between cultivations. Based on the four dates of cultivation and precipitation events, it was determined that approximately 1.35 inches of moisture was lost due to tillage. The amount of effective precipitation from May 19-October 25, 1984 was 3.57 inches. With run-off set at zero, a crude potential loss due to deep percolation and evaporation may be computed as follows:

Maximum Stored Soil Moisture	=	4.20 inches
Effective Rainfall	+	3.57 inches
	=	7.77
Tillage Soil Moisture Loss	-	1.35
	=	6.42
Fall Moisture Content (November, 1984)	-	3.15
Moisture Loss Due to Evaporation or Deep Percolation	=	3.27

TABLE 4: Percent Moisture of Field Capacity for the Summer Fallow Check Field for the Weeks of August 10-October 25, 1984, and Effective Rainfall Measurements, Chartier Site. Based on Field and Appearance Method.

DATE	MOISTURE PERCENT FIELD CAPACITY	EFFECTIVE RAINFALL (INCHES)
8/10	50	0
8/16	45	0
9/2	55	.49
9/5	50	0
9/9	48	.08
9/12	45	0
9/16	43	0
9/19	42	0
9/23	45	.15
9/26	45	.08
10/4	50	0
10/7	45	0
10/10	43	0
10/14	40	0
10/25	75	.39

Theoretically, 3.27 inches per acre of water was lost to deep percolation and/or evaporation from the summer fallow field. Evaporation rates on bare soil are closely approximated by water loss from the evaporation pan. As the available soil moisture decreases, the osmotic and capillary forces tightly retain the remaining water. With decreased upward diffusion a dry soil mulch develops and evaporation rates become negligible. With these concepts in mind, evaporation from the fallow field was calculated to be approximately 1.265 inches for the growing season. Subtracting this value from the 3.27 inches of moisture that was attributed to deep percolation and evaporation leaves us with 2.01 inches of soil moisture lost to deep percolation. This would contribute 54,575 gallons/acre or 6,439,911 gallons of water for the 118 acres of fallow ground. These calculations indicate recharge to ground water aquifers is significant under fallow conditions. At freezeup, the soil moisture content was at 75 percent of field capacity. Therefore, the soil should be able to accumulate another 1.05 inches of water over the winter months.

<u>Summary</u>

Due to the drought conditions during the 1984 cropping season there was a large variance between the crop water use rates determined by the evaporation pan method versus those calculated by the "Feel and Appearance" method. The crop water use rates, as determined by evaporation pan were 11.62" (Chartier alfalfa), 13.16" (Chartier barley), 15.59" (Johnson barley), 11.20" (Johnson winter wheat) and 15.59" (Johnson spring wheat), respectively. During the 1984 cropping season, water was severely limited. This situation discouraged full development of the root systems so actual evapotranspiration was significantly lower than the potential evapotransporation. Under the environmental limitations imposed during 1984, the crop water use rates, as calculated by the "Feel and Appearance" method, more closely approximate actual evapotranspiration. These rates were 5.18" (Chartier alfalfa), 5.60" (Chartier barley), 6.86" (Johnson barley), 6.65" (Johnson winter wheat) and 6.86" (Johnson spring wheat).

The key point to note, is that for 1984, the alfalfa and cropped fields used all the available moisture over the growing season (after accounting for the stored soil moisture remaining at harvest time). The alfalfa will prove to be more efficient in the long term. A perennial, such as alfalfa, has an established root system and as soon as air and soil temperatures warm up, the alfalfa can begin regrowth. On the other hand, spring small grains have a lag time to allow for root development before they can efficiently utilize the seasonal precipitation and

stored soil moisture. In regards to the fallow conditions on Chartier's field, up to 6,439,911 gallons of water from the 118 acres of fallow were able to recharge the deeper ground water systems. The remarkable fact is that this volume of water was lost to deep percolation in a drought year.

Future Study

The two sites will be monitored for another four years or for as long as funds permit. A more sophisticated weather station has been set up at the Chartier site. Evapotranspiration rates will be calculated this upcoming year in accordance with the procedures outlined in this report. Additional verification of actual evapotranspiration rates will be accomplished by checking crop water use rates against other methods that make use of meteorologic data (i.e., daily maximum-minimum temperatures, wind velocity and solar radiation). Also, stored soil mois-depletion will be checked by gravimetric soil analysis - one set of samples to be analyzed in the spring and another following harvest.

Since the focus of this study is twofold: 1) to verify the effectiveness of intensive vegetation management and 2) to get a quantitative "feel" for ground water recharge from the benches, a number of empirical formulae are being looked at to try to develop a feasible model of ground water recharge.

allowed soil moisture. In regards to the fallow conditions on Charlie's Field, up to 6,439,957 gallons of water from the 118 acres of fallow were able to recharge the deeper ground water system. The remarkable fact is that this volume of water was lost to deep percolation in a drought year.

Future Study

The two sites will be monitored for another four years or for as long as funds permit. A more sophisticated weather station may then be set up at the Charlie site. Evapotranspiration rates will be calculated this upcoming year in accordance with the procedures outlined in this report. Additional verification of actual evapotranspiration rates will be accomplished by checking crop water use rates against other methods that make use of meteorologic data (ext., daily maximum-minimum temperature, wind velocity and solar radiation). Also, stored soil moisture depletion will be checked by gravimetric soil analysis. One set of samples to be analyzed in the spring and another following harvest.

Since the focus of this study is twofold: 1) to survey the [illegible] of intensive vegetation management and 2) to get a quantitative 'feel' for ground water recharge from the benches, a number of empirical formulas are being looked at in try to develop a feasible model of ground water recharge.

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APPENDICES

APPENDIX A

CHARTIER SITE LOCATION MAP

JOHNSON SITE LOCATION MAP

APPENDIX B

TCD WELL LOGS, CHARTIER AND JOHNSON SITES

SOIL SERIES DESCRIPTIONS, CHARTIER AND JOHNSON SITES

APPROXIMATE AVAILABLE WATER HOLDING CAPACITIES PER SOIL TEXTURE

LOG OF TEST HOLES

OPERATOR: Ernie Chartier

SITE NO. SS-1

COUNTY: Cascade

OWNER Ernie Chartier

LOCATION: T. 19 R. 4 Sec. 26

DATE 5/17/83

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	HOLE DEPTH TO FT.	DESCRIPTION OF MATERIALS		Moisture Content
1	Coulee N. Side of Field	0	5	Loam	Cased 7 feet	Very Moist
		5	6½	Sandstone		
2	S of 1 in bottom	0	1	Loam	Cased 5 Feet	Very Moist
	3 strips W of poles	1	2	Clay loam		Very Moist
		2	4	Sandstone		
3	SW of 2 on ridge	0	2½	Loam	Not Cased	Very Moist
		2½	3	Sandstone		
4	SW of 3 along fence	0	4	Loam some gravels	Cased 5½ Feet	Very Moist
-		4	4	Sandstone		

TRIANGLE CONSERVATION DISTRICT

LOG OF TEST HOLES

COUNTY: Cascade		OPERATOR: Ernie Chartier	SITE NO. SS-1
LOCATION: T. 19 R. 4 Sec. 26	DATE 5/17/83	OWNER Ernie Chartier	

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	TO FT.	DESCRIPTION OF MATERIALS		Moisture Content
5	SE of 4 on ridge	0	2	Loam	Not Cased	Wet
	3 strips W of poles	2	2½	Sandstone lens		
		2½	4½	Loam		Wet
		4½	4½	Sandstone		
				Section 35		
	S of 4 few hundred	0	1	Loam		Moist
	yards N of field	1	2	Gravelly loam		Slightly Moist
	S edge	2	9	Gravelly loamy sand		Moist
		9	9	Sandstone		
7	Next to power	0	2	Loam	Cased 8 Feet	Moist
-	poles NE of 5	2	6	Clay loam with mottling some shale		Wet
		6	6½	Bentonite and shale		Moist
		6½	6½	Sandstone		

TRIANGLE CONSERVATION DISTRICT

LOG OF TEST HOLES

OPERATOR: Ernie Chartier SITE NO. SS-1

COUNTY: Cascade OWNER Ernie Chartier

LOCATION: T. 19 R. 4 Sec. 26 DATE 5/17/83

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	TO FT.	DESCRIPTION OF MATERIALS		Moisture Content
8	2 poles N of 7	0	2	Loam	Cased 10 Feet	Moist
	and $1\frac{1}{2}$ strips in	2	5	Clay loam gravel lens $2\frac{1}{2}$ feet		Very Moist
	draw	5	7	Clay		Slightly Moist
		7	$8\frac{1}{2}$	Sandstone		
				Section 35		
	E & S of 6 in	0	2	Clay loam	Cased 6 feet	Moist
	grass along	2	3	Clay with weathered shale and shale bands		Moist
	fence	3	4	Clay loam		Moist
		4	5	Sandy loam and fractured sandstone		Slightly Moist
		5	5	Sandstone		
				Section 26		
10	Between 4 & 6	0	2	Loam	Cased 13 feet	Very Moist
	W of 5	2	4	Clay with weathered shale lens		Moist
		4	$8\frac{1}{2}$	Loam		Moist
		$8\frac{1}{2}$	11	Sandy shale and sandstone intermixed		

TRIANGLE CONSERVATION DISTRICT

LOG OF TEST HOLES

COUNTY: Cascade

LOCATION: T. 19 R. 4 Sec. 26

DATE 5/18/83

OPERATOR: Ernie Chartier

SITE NO. SS-1

OWNER Ernie Chartier

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	HOLE DEPTH TO FT.	DESCRIPTION OF MATERIALS	Moisture Content
11	SW of 3 in draw	0	1	Loam Cased 9 feet	Moist
	on field edge	1	3	Clay loam	Moist
		3	5	Bentonite clay - gray some sandy shale @ 5 feet	Moist
		5	7	Silt stone	
		7	7	Sandstone	
				NOTE: There is fractured sandstone mixed throughout most of the well profiles - indicating a fractured permeable layer before a more consolidated sandstone is reached.	

TRIANGLE CONSERVATION DISTRICT

LOG OF TEST HOLES

OPERATOR: Gene Johnson — SITE NO. SS-2

COUNTY: Cascade — OWNER: Gene Johnson

LOCATION: T. 19 R. 5 Sec. 7 & 8 — DATE: 6/1/83

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	HOLE DEPTH TO FT.	DESCRIPTION OF MATERIALS	Moisture Content
1	Head of coulee	0	1	Channery loam gravels mixed throughout Cased 6½ feet	Dry
	just NE of grass	1	4	Silt loam	Moist
	along fence	4	5	Silty clay loam some weathered shale	Moist
		5	6	Sandy shale and siltstone	
		6		Sandstone - siltstone	
2	W. side of grass	0	3	Silt loam	Slightly Moist
	in large coulee	3	5	Loam with fractured sandstone	Moist
		5		Sandstone	
3	Next coulee west along	0	1	Silt loam gravels mixed throughout Cased 8 feet	Dry
	E. side	1	6	Silty clay loam	Wet
		6	6½	Clay loam (red)	Moist
		6½		Sandy shale (red)	Moist

TRIANGLE CONSERVATION DISTRICT

OPERATOR: Gene Johnson | SITE NO. SS-2

OWNER Gene Johnson

COUNTY: Cascade

LOCATION: T. 19 R. 5 Sec. 7 & 8 | DATE 6/1/83

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	TO FT.	DESCRIPTION OF MATERIALS		Moisture Content
4	Range W of field	0	1	Loam	Not Cased	Dry
	above acid spoil in	1	2	Silty loam mixtures of sand, sandy loam - very mixed		Dry
	field below	2		Sandstone - siltstone		Dry
5	Next to fence	0	1	Loam	Cased 7 feet	Dry
	N. end of field	1	4	Silt loam hard gravel - cobble layer @ 3 feet		Dry
		4	6	Silty clay loam mixed gravels throughout		Dry
		6		Sandstone		
6	Straight S. of 5	0	1	Silty clay loam	Not Cased	Dry
	on ridge	1	2	Gravelly sandy loam		Moist
		2	4	Silty clay loam some weathered shale lenses		Moist
		4		Sandstone - siltstone		

Stockett-Sand Coulee

OPERATOR: Gene Johnson

SITE NO. SS-2

COUNTY: Cascade

OWNER Gene Johnson

LOCATION: T. 19 R. 5 Sec. 7 & 8

DATE 6/1/83

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	HOLE DEPTH TO FT.	DESCRIPTION OF MATERIALS	Moisture Content
7	SE of 6 W. of	0	$1\frac{1}{2}$	Silty clay loam Cased 10 feet	Dry
	Gobblers Knob	$1\frac{1}{2}$	2	Gravelly clay loam	Dry
		2	3	Compacted sandy loam	Dry
		3	7	Interbedded sandstone, siltstone and shale	
8	S. of 7 SW of	0	$2\frac{1}{2}$	Clay loam Wet @ 2 feet	Moist
	knob on ridge	$2\frac{1}{2}$		Siltstone	
				6/2/83	
9	Edge of grass	0	2	Gravelly loam Not Cased	Dry
	S. of 1	2	3	Gravelly sandy loam	Dry
		3	5	Clay loam	Moist
-		5		Sandstone - siltstone	

TRIANGLE CONSERVATION DISTRICT

LOG OF TEST HOLES

Stockett-Sand Coulee		OPERATOR: Gene Johnson	SITE NO. SS-2
COUNTY: Cascade		OWNER Gene Johnson	
LOCATION: T. 19 R. 5 Sec. 7 & 8	DATE 6/2/83		

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	HOLE DEPTH TO FT.	DESCRIPTION OF MATERIALS	Moisture Content
10	S. of 9 on flat	0	2	Silty clay loam Cased $8\frac{1}{2}$ feet	Slightly Moist
	NE of knob	2	4	Shale	Slightly Moist
		4	$6\frac{1}{2}$	Weathered shale with bentonite some shale chips	Slightly Moist
		$6\frac{1}{2}$		Sandstone - siltstone	
11	Above water seep E. of	0	$2\frac{1}{2}$	Silty clay loam mixed with fractured sandstone	Dry
	knob S. of 10	$2\frac{1}{2}$	4	Sandy loam	Dry
		4	$4\frac{1}{2}$	Siltstone	
12	Spr. feeding Reser.	0	4	Silty clay loam some shale @ 2 feet Cased $21\frac{1}{2}$ feet	Wet
		4	$6\frac{1}{2}$	Sandy loam fractured sandstone @ 5 feet Saturated @ 6 feet	Wet
		$6\frac{1}{2}$	15	Weathered shale 8 feet on periodic layers of hard shale & lignite lenses	
		15	18	Shale	

TRIANGLE CONSERVATION DISTRICT

LOG OF TEST HOLES

Stockett-Sand Coulee | OPERATOR: Gene Johnson | SITE NO. SS-2

COUNTY: Cascade | OWNER Gene Johnson

LOCATION: T. 19 R. 5 Sec. 7 & 8 | DATE 6/2/83

HOLE NO.	Hole Location	HOLE DEPTH FROM FT.	HOLE DEPTH TO FT.	DESCRIPTION OF MATERIALS			Moisture Content
13	S. of knob	0	2½	Silty clay loam		Cased 16 feet	Dry
	between 8 & 12	2½	5	Soft shale			Moist
		5	6½	Sandy loam			Moist
		6½	7	Lignite	Free Water		
		7	13	Soft shale			
14	Top of knob	0	10	Silty clay loam		Not Cased	Dry
		10	13	Shale and siltstone (red)			Dry
15	Wet spots NW of knob	0	1	Silty clay loam		Cased 6½ feet	Wet
		1	2½	Gravelly sandy loam			Dry
		2½	4	Silty clay loam			Slightly Moist
		4	4½	Loam with sandstone - siltstone pieces			
		4½		Sandstone - siltstone			

TRIANGLE CONSERVATION DISTRICT

SOIL SERIES DESCRIPTIONS - CHARTIER AND JOHNSON SITES

After: Cascade County SCS Soil Survey

BIG TIMBER SERIES

The Big Timber series consists of shallow, well drained soils formed in interbedded shale and sandstone of mixed mineralogy, and found on uplands. They are only 10 to 20 inches deep over interbedded shale and sandstone. Slopes are 8 to 70 percent. The elevation is 3,500 to 5,000 feet. The native vegetation is mainly bluebunch wheatgrass, rough fescue, green needlegrass, and forbs and shrubs. The mean annual precipitation is 14 to 16 inches. The mean annual air temperature is 43 to 45 degrees F. The growing season is 105 to 135 days.

Typically the surface layer is reddish brown clay loam about 6 inches thick. The underlying material is reddish brown clay loam about 9 inches thick. Below this is platy shale bedrock. The soil is calcareous throughout.

Permeability is moderately slow. The available soil moisture holding capacity is very low. Reaction is moderately alkaline.

These soils are mainly used as rangeland.

Typical profile of Big Timber clay loam in an area of Big Timber-Castner complex, 30 to 70 percent slopes, in native grass, about 1,500 feet north and 100 feet east of southwest corner sec. 31, T.19N., R.7E.

A1- 0 to 6 inches; reddish brown (5YR 4/3) clay loam, dark reddish brown (5YR 3/3) moist; strong fine granular structure; hard, friable, sticky, plastic; many fine and few medium roots; many fine pores; 5 to 10 percent flat sandstone fragments; moderately alkaline; strongly effervescent; clear wavy boundry.

C1- 6 to 15 inches; reddish brown (2.5YR 5/4) clay loam; dark reddish brown (2.5YR 3/4) moist; weak fine blocky structure; hard, friable, sticky, plastic; common fine and few medium roots; many fine pores; 15 percent fine sandstone and shale fragments; strongly effervescent; moderately alkaline; gradual smooth boundary.

C2r- 15 t 40 inches; reddish brown (2.5YR 5/4) platy clay loam shale, dark reddish brown (2.5YR 3/4) moist; some interbedded thin layers of hard sandstone.

Depth to interbedded shale and sandstone ranges from 10 to 20 inches. The volume of coarse fragments throughout the soil ranges from 0 to 25 percent. Reaction is mildly or moderately alkaline throughout the soil.

21-Big Timber-Castner complex, 8 to 30 percent slopes. This map unit consists of strongly rolling and hilly soils on sedimentary uplands. It is about 55 percent Big Timber clay loam and 30 percent Castner channery loam.

Big Timber clay loam occupies the reddish brown clay loam shale areas. Castner channery loam occupies sandstone ledges. About 15 percent of the unit is included areas of Darret and Timberg soils.

The Big Timber soil in this unit has a profile similar to the one described as typical of the series. The Castner soil has a profile similar to the one described as typical of the Castner series, but it is generally reddish brown or brown.

Surface runoff is rapid. The erosion hazard is slight from wind and is moderate or severe from water.

This unit is used mostly for range. Capability unit VIe-1 dryland; Shallow range site, 15- to 19-inch precipitation zone. Big Timber soil in windbreak suitability group 3M if slope is less than 15 percent, group 4-0 if more than 15 percent. Castner soil in windbreak suitability group 4-1.

CASTNER SERIES

The Castner series consists of shallow, well drained soils formed in material weathered from shattered sandstone and igneous bedrock. These soils are on uplands at elevations of 3,350 to 4,600 feet. Slopes are 0 to 60 percent. The native vegetation is mainly bluebunch wheatgrass, rough fescue, green needlegrass, and forbs and shrubs. The mean annual precipitation is 14 to 18 inches. The mean annual air temperature is 42 to 45 degrees F. The growing season is 105 to 135 days.

In a representative profile the surface layer is about 6 inches of dark grayish brown channery sandy loam and 4 inches of brown, calcareous very channery loam. The underlying material is pale brown, calcareous extremely channery loam 6 inches thick. Below 16 inches is calcareous sandstone.

Permeability is moderate. The available soil moisture holding capacity is very low. Reaction is neutral or mildly alkaline in the upper 10 inches and moderately alkaline below.

These soils are mainly used for dryland crops and range.

Typical profile of Castner channery loam, in an area of Castner-Reeder complex, 4 to 35 percent slopes, in native gras, 300 feet west and 1,030 feet south of northeast corner sec. 18, T.20N., R.3W.

A11- 0 to 6 inches; dark grayish brown (10YR 4/2) channery sandy loam, very dark grayish brown (10YR 3/2) moist; moderate medium granular structure; soft, very friable, slightly sticky, nonplastic; 25 percent sandstone fragments mainly smaller than 6 inches but with some flagstones; neutral; clear smooth boundary.

A12- 6 to 10 inches; (20YR 4/3) very channery loam, very dark grayish brown, (10YR 3/2) moist; moderate medium granular structure; slightly hard, very friable, slightly sticky, nonplastic; many fine and very fine roots and pores; 50 percent sandstone fragments of flagstone size and smaller;

lime crusts on undersides of some fragments; slightly effervescent; mildly alkaline; clear smooth boundary.

Cca- 10 to 16 inches; pale brown (10YR 6/3) extremely channery loam, dark grayish brown (10YR 4/2) moist; massive; slightly hard, very friable, slightly sticky, slightly plastic; many fine and very fine roots with a root mat at 16 inches; 75 percent sandstone fragments of flagstone size and smaller; thick lime crusts and pendants; strongly effervescent; moderately alkaline; abrupt wavy boundary.

R- 16 inches; layered shattered calcareous sandstone with lime crusts at the contact of fractures.

IPANO SERIES

The Ipano series consists of moderately deep, well drained soils formed in alluvium or loess over sandstone. These soils are on uplands. They are only 20 to 40 inches deep over hard sandstone. Slopes are 0 to 15 percent. The elevation is 3,300 to 4,300 feet. The native vegetation is mainly rough fescue, bluebunch wheatgrass, Columbia needlegrass, and forbs and shrubs. The mean annual precipitation is 14 to 19 inches. The mean annual temperature is 43 to 45 degrees F. The growing season is 105 to 135 days.

Typically the surface layer is grayish brown, calcareous loam about 8 inches thick. The subsoil is light brownish gray and light gray, calcareous silt loam about 11 inches thick. The substratum is light brownish gray, calcareous gravelly loam and pale brown, calcareous channery loam about 15 inches thick. Below 34 inches is hard sandstone.

Permeability is moderate to 34 inches. The available soil moisture holding capacity is low or moderate. Reaction is mildly alkaline in the upper 8 inches and moderately alkaline below.

These soils are used mainly for dryland crops and range.

Typical profile of Ipano loam, in cropland, 460 feet west and 180 feet north of the center of sec. 28, T.20N., R.3E.

Ap- 0 to 8 inches; grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 3/2) moist; moderate fine and very fine granular structure; slightly hard, very friable, sticky plastic; slightly effervescent; mildly alkaline; abrupt wavy boundary.

B2ca-8 to 13 inches; light brownish gray (10YR 6/2) silt loam, dark grayish brown (10YR 4/2) moist; moderate medium prismatic structure parting to weak medium and fine subangular blocky; hard, very friable, sticky, plastic; common fine and very fine roots; many fine and very fine pores;

common fine soft masses of lime; strongly effervescent; moderately alkaline; clear wavy boundary.

B3ca-13 to 19 inches; light gray (10YR 7/2) silt loam, dark grayish brown (10YR 4/2) moist; weak coarse prismatic structure parting to weak medium and fine subangular blocky; hard, very friable, sticky, plastic; common fine and very fine roots; many fine and very fine pores; common soft masses and filaments of lime; few angular sandstone fragments; violently effervescent; moderately alkaline; clear wavy boundary.

11C1-19 to 24 inches; light brownish gray (10YR 6/2) gravelly loam, dark grayish brown (10YR 4/2) moist; weak medium and fine subangular blocky structure; hard, very friable, sticky, plastic; common fine and very fine roots; many fine and few medium pores; common nodules of lime; 15 percent by volume of angular sandstone fragments; violently effervescent; moderately alkaline; gradual wavy boundary.

11C2ca-24 to 34 inches; pale brown (10YR 6/3) channery loam, brown (10YR 5/3) moist; hard, very friable, nonsticky, nonplastic; 30 percent by volume of sandstone fragments; strongly effervescent; moderately alkaline; gradual wavy boundary.

11R- 34 inches; hard fractured sandstone.

Depth to bedrock ranges from 20 to 40 inches. The average volume of sandstone coarse fragments in the 11Cca horizon is 15 to 30 percent. Reaction of the A and B horizons ranges from mildly to moderately alkaline.

108-Ipano-Ticell loams, 4 to 20 percent slopes. This map unit consists of gently rolling and strongly rolling soils on uplands. It is about 55 percent Ipano loam and about 20 percent Ticell loam. The Ipano loam occupies the plane slopes and concave areas, and the Ticell loam occupies convex slopes and ridges. About 10 percent of the unit is included areas of Castner soils on convex slopes and ridges. About 15 percent is Absarokee and Work soils on smooth slopes and in swales.

Surface runoff is medium. The erosion hazard is moderate from both wind and water.

This unit is suited to wheat, barley, hay, and pasture under dryland management. It is well suited to range. Capability unit llle-4 dryland. Ipano soil in Silty range site, 15- to 19-inch precipitation zone; windbreak suitability group 2M. Ticell soil in Shallow range site, 15- to 19-inch precipitation zone; windbreak suitability group 3M.

TICELL SERIES

The Ticell series consists of shallow, well drained soils formed in alluvium of mixed mineralogy. These soils are on uplands at elevations of 3,300 to 4,400 feet. They are only 10 to 20 inches deep over hard sandstone. Slopes are 0 to 10 percent. The native vegetation is mainly bluebunch wheatgrass, rough fescue, mountain brome, and forbs and shrubs. The mean annual precipitation is 14 to 19 inches. The mean annual air temperature is 43 to 45 degrees F. The growing season is 105 to 135 days.

Typically the surface layer is grayish brown loam about 6 inches thick. The subsoil is light gray, calcareous silt loam about 5 inches thick. The substratum is light gray, calcareous silt loam about 4 inches thick over hard sandstone.

Permeability is moderate. The available soil moisture holding capacity is very low. Reaction is mildly or moderately alkaline in the upper 6 inches and moderately alkaline below.

These soils are used mainly for dryland crops and range.

Typical profile of Ticell loam in cropland, 800 feet west and 180 feet north of the center of sec. 28, T.20N., R.3E.

Ap- 0 to 6 inches; grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 3/2) moist; moderate fine and very fine granular structure; slightly hard, very friable, slightly sticky, slightly plastic; slightly effervescent; moderately alkaline; abrupt wavy boundary.

B2ca-6 to 11 inches; light gray (10YR 7/2) silt loam, brown (10YR 5/3) moist; moderate medium prismatic structure parting to weak fine and medium subangular blocky; hard, very friable, slightly sticky, slightly plastic; common fine and very fine roots; many fine and very fine pores; common soft masses of lime; violently effervescent; moderately alkaline; clear wavy boundary.

Cca- 11 to 15 inches; light gray (10YR 7/2) silt loam, brown (10YR 5/3) moist; weak coarse prismatic structure; hard, very friable, slightly sticky, slightly plastic; common fine and very fine roots; many fine and very fine pores; 5 percent fine sandstone fragments; common soft masses of lime; violently effervescent; moderately alkaline; abrupt wavy boundary.

IIR- 15 inches; indurated sandstone

Depth to sandstone ranges from 10 to 20 inches. The volume of coarse fragments throughout the soil ranges from 0 to 30 percent. The Ap horizon is mildly or moderately alkaline.

DARRET SERIES

The Darret series consists of moderately deep, well drained soils in material weathered from interbedded shale and sandstone. These soils are on uplands. They are only 20 to 40 inches deep over interbedded shale and sandstone. Slopes are 2 to 20 percent. The elevation is 3,300 to 4,800 feet. The native vegetation is mainly rough fescue, bluebunch wheatgrass, green needlegrass, and forbs and shrubs. The mean annual precipitation is 13 to 17 inches. The mean annual air temperature is 43 to 45 degrees F. The growing season is 105 to 135 days.

Typically the surface layer is dark reddish gray silty clay loam about 7 inches thick. The subsoil is reddish brown silty clay and clay loam about 11 inches thick. The substratum is reddish brown, calcareous clay loam about 10 inches thick. Below 28 inches is dark reddish brown, calcareous shale and sandstone.

Permeability is slow. The available soil moisture holding capacity is low. Reaction is neutral in the upper 7 inches and mildly or moderately alkaline below.

These soils are used for either dryland crops or range.

Typical profile of Darret silty clay loam, in cropland, 1,320 feet north and 1,050 feet west of southeast corner SW¼ sec. 16, T.18N., R.6E.

Ap- 0 to 7 inches; dark reddish gray (5YR 4/2) silty clay loam, dark reddish brown (5YR 2/2) moist; moderate fine granular structure; slightly hard, friable, sticky, plastic; common fine and very fine roots; many very fine and fine pores; neutral; abrupt smooth boundary.

B2t- 7 to 11 inches; reddish brown (5YR 4/3) silty clay, dark reddish brown (5YR 3/3) moist; moderate medium prismatic structure parting to strong fine blocky; hard, friable, sticky, plastic; common fine and very fine roots; many fine and very fine pores; thin continuous clay films on ped faces; dark reddish brown (5YR 2/2) moist; organic stains on prism faces; mildly alkaline; clear wavy boundary.

B3- 11 to 18 inches; reddish brown (2.5YR 4/4) clay loam, dark reddish brown (2.5YR 3/4) moist; strong fine blocky structure; hard, friable, sticky, plastic; common fine and very fine roots; many fine and very fine pores; thin patchy clay films on ped faces; slightly effervescent; moderately alkaline; gradual wavy boundary.

C1ca-18 to 28 inches; reddish brown (2.5YR 5/4) clay loam, dark reddish brown (2.5YR 3/4) moist; moderate medium blocky structure; hard, friable, sticky, plastic; few fine and very fine roots;

many fine and very fine pores; common medium and coarse soft masses of lime; 10 percent shale and sandstone; strongly effervescent; moderately alkaline; gradual wavy boundary.

C2r- 28 inches; dark reddish brown (2.5YR 3/4) calcareous interbedded shale and sandstone.

The B2t horizon is silty clay loam or silty clay. Depth to bedrock is 20 to 40 inches.

49-Darret-Castner complex, 2 to 8 percent slopes. This map unit consists of undulating and gently rolling soils on sedimentary uplands. It is about 60 percent Darret silty clay loam and 25 percent Castner channery loam. The Darret silty clay loam is on smooth slopes over reddish colored shale beds. The Castner channery loam is on the convex slopes, ridges, and knolls. About 15 percent of the unit is included areas of Big Timber and Sinnigam soils.

Surface runoff is medium. The erosion hazard is slight from wind and is moderate from water.

This unit is suited to wheat, barley, hay, and pasture under dryland management. It is also suited to range. Capability unit IIIe-9 dryland. Darret soil in Clayey range site, 15- to 19-inch precipitation zone; windbreak suitability group 2M. Castner soil in Shallow range site, 15- to 19-inch precipitation zone; windbreak suitability group 4-1.

Table 5. Approximate available water capacities of soil textured classes commonly occurring as either surface, subsurface, or lower horizon materials.

Soil Texture Classes	Surface Soil 0 - 12"	Subsoil 12 - 36"	Lower Horizons 36 - 60"
	Available Water Capacities		
	Inches per inch of soil		
Coarse sand and gravel	.04 to .06	.03 to .05	.02 to .04
Sands	.07 to .09	.06 to .08	.05 to .07
Fine sands	.06 to .12	.06 to .11	.05 to .09
Loamy sands	.10 to .12	.09 to .11	.08 to .10
Loamy fine sand	.10 to .12	.10 to .13	.08 to .12
Sandy loams	.13 to .15	.12 to .14	.11 to .13
Fine sandy loams	.16 to .18	.15 to .17	.14 to .16
Loams and very fine sandy loams	.20 to .22	.17 to .19	.17 to .19
Silt loams	.22 to .24	.20 to .22	.20 to .22
Silty clay loams	.18 to .23	.16 to .20	.16 to .20
Sandy clay loams	.18 to .20	.16 to .18	.15 to .17
Clay loams	.17 to .19	.15 to .19	.14 to .16
Silty clays	.15 to .18	.14 to .17	.13 to .15
Clays	.15 to .18	.14 to .17	.13 to .15

From: J.W. Bauder, Scheduling Irrigation in Montana. Montana Cooperative Extension Service.

APPENDIX C

CHARTIER FERTILIZER RECOMMENDATIONS

PHOSPHATE BUILD AND MAINTENANCE PROGRAM

Ernie Chartier
Sec. 24 & 25
1984

FERTILIZER RECOMMENDATIONS

Feed Barley

On 1983 summer fallow:

Bulk rate to be applied (lb/ac	Material		Actual rate N	P_2O_5	K_2O
50*	18-46-0		9	23	
121	34-0-0		41		
50**	0-0-60				30
		Total	50	23	30

On 1983 cropland:

Bulk rate to be applied (lb/ac)	Material		Actual rate N	P_2O_5	K_2O
50*	18-46-0		9	23	
212	34-0-0		72		
50**	0-0-60				30
		Total	81	23	30

Note: based on a yield goal of 40 bu/ac

Spring Wheat

On 1983 summer fallow:

Bulk rate to be applied (lb/ac)	Material		Actual rate N	P_2O_5	K_2O
50*	18-46-0		9	23	
85	34-0-0		29		
50**	0-0-60				30
		Total	38	23	30

On 1983 cropland:

Bulk rate to be applied (lb/ac)	Material		Actual rate N	P_2O_5	K_2O
50*	18-46-0		9	23	
176	34-0-0		60		
50**	0-0-60				30
		Total	69	23	30

Note: based on a yield goal of 30 bu/ac

Winter Wheat

Seeded and fertilized with 70 lb/ac 11-51-0, Fall 1983 (equals 8 lb/ac actual N)

'83 Fallow: apply 88 lb/ac 34-0-0 (30 lb actual N)

'83 Cropland: apply 179 lb/ac 34-0-0 (61 lb actual)

Note: based on a yield goal of 30 bu/ac

*Place with seed

**Optional, try on a few acres to see if there is a response to potassium.

Ernie Chartier
Sec. 24 & 25
1984

Summary of Fertilizer Test Results

<u>1983 Cropland</u>

N = 14 lb/ac
P = 20 ppm
K = 242 ppm

<u>1983 Recrop</u>

N = 11.5 lb/ac
P = 19.5 ppm
K = 242 ppm

<u>1983 Fallow</u>

N = 33 lb/ac
P = 16 ppm
K = 201 ppm

Phosphorus (P) Potassium (K) Soil Test Results (MSU Lab)
Ernie Chartier

Sample #	C-1	C-2	C-3	C-4	C-5
P	8 ppm	7 ppm	13 ppm	13 ppm	12 ppm
K	229 ppm	181 ppm	242 ppm	242 ppm	363 ppm

Sample #	C-6	C-7	C-8	C-9	C-10
P	15.5 ppm	9 ppm	23 ppm	7 ppm	13 ppm
K	350 ppm	229 ppm	240 ppm	290 ppm	254 ppm

Sample #	C-11	C-12
P	12.1 ppm	15 ppm
K	360 ppm	302 ppm

Average P = 12.3 ppm
Average K = 273.5 ppm

PHOSPHORUS BUILD AND MAINTENANCE (see attached sheet)

Medium fine texture soil $\frac{16.1 - 12.3}{.228}$ = 16.7 x 2.3 = 38 lbs of P_2O_5
round up to 40 lbs P_2O_5

For every 1 ton of alfalfa removed approximately 10 lbs of P_2O_5 is removed (Fertilizer Handbook, 1972).

The yield is estimated to be 2 tons/acre/year for the soil and climatic conditions.

100 lbs. of additional P_2O_5 (2 ton x 10 lbs. P_2O_5 removed x 5 yrs.) needs to be added for maintenance.

Total actual P_2O_5 required = 40 lb (buildup) + 100 lb (maintenance) = 140 lb.

275 lb bulk material using 11-51-0 fertilizer, supplies 30 lbs of actual N and 140 lbs of actual P_2O_5.

The average potassium value is 274 ppm, a level adequate enough to require no additional potassium.

PHOSPHATE BUILD AND MAINTENANCE PROGRAM

The amount of phosphate fertilizer required to build the 0-6" depth or plow layer to 16 ppm should be applied in the first year and subsequently maintained by applications equal to crop removal rates.

SOIL TEST - OLSEN - Reported in ppm w/16 ppm as optium.

CROP REMOVAL RATE:

Wheat/bu removes	.625 lbs P_2O_5 in the grain
	.125 lbs P_2O_5 in straw*
Barley/bu removes	.35 lbs P_2O_5 in the grain
	.10 lbs P_2O_5 in the straw*
Alfalfa removes	10 lbs P_2O_5 per Ton

Moderately -coarse textured soil

$$\frac{16.1 - \text{soil test (ppm)}}{.282} = \text{lbs. of P** to raise soil test to 16 ppm.}$$

Moderately - fine textured soil

$$\frac{16.1 - \text{soil test (ppm)}}{.228} = \text{lbs. of P** to raise soil test to 16 ppm.}$$

*If straw is not removed from the field, then ignore.
**Convert P to P_2O_5: lbs. of P x 2.3 = lbs. of P_2O_5.

EXAMPLE

Soil Texture: Clay loam (mod. fine)
Soil Test P: 12 ppm
Last year crop: wheat 40 bu.

$$\frac{16.1 - 12.0}{.228} = 18 \text{ lbs. P} \times 2.3 = 41 \text{ lbs. } P_2O_5$$

41 lbs. P_2O_5 needed to bring soil P up to 16 ppm.

40 bu. (last crop removal) x .625 = 25 lbs. P_2O_5

THEREFORE need to add 66 lbs P_2O_5 for this year's crop.
Once the field is brought up to 16 ppm, than the amount of P_2O_5 to be added will only be the maintenance for the next crop.

ALFALFA

Soil Texture: clay loam
Soil Test P: 12 ppm
Yield Goal: 2 Ton/Ac.

$$\frac{16.1 - 12.0}{.228} = 18 \text{ lbs P} \times 2.3 = 41 \text{ bls } P_2O_5$$

2 tons/ac x 5 years* x 10 lbs removed/ton = 100 lbs P_2O_5

Total Needs: 41 lbs for build to 16 ppm
+100 lbs for crop removal for a 5 yr. stand

141 lbs P_2O_5

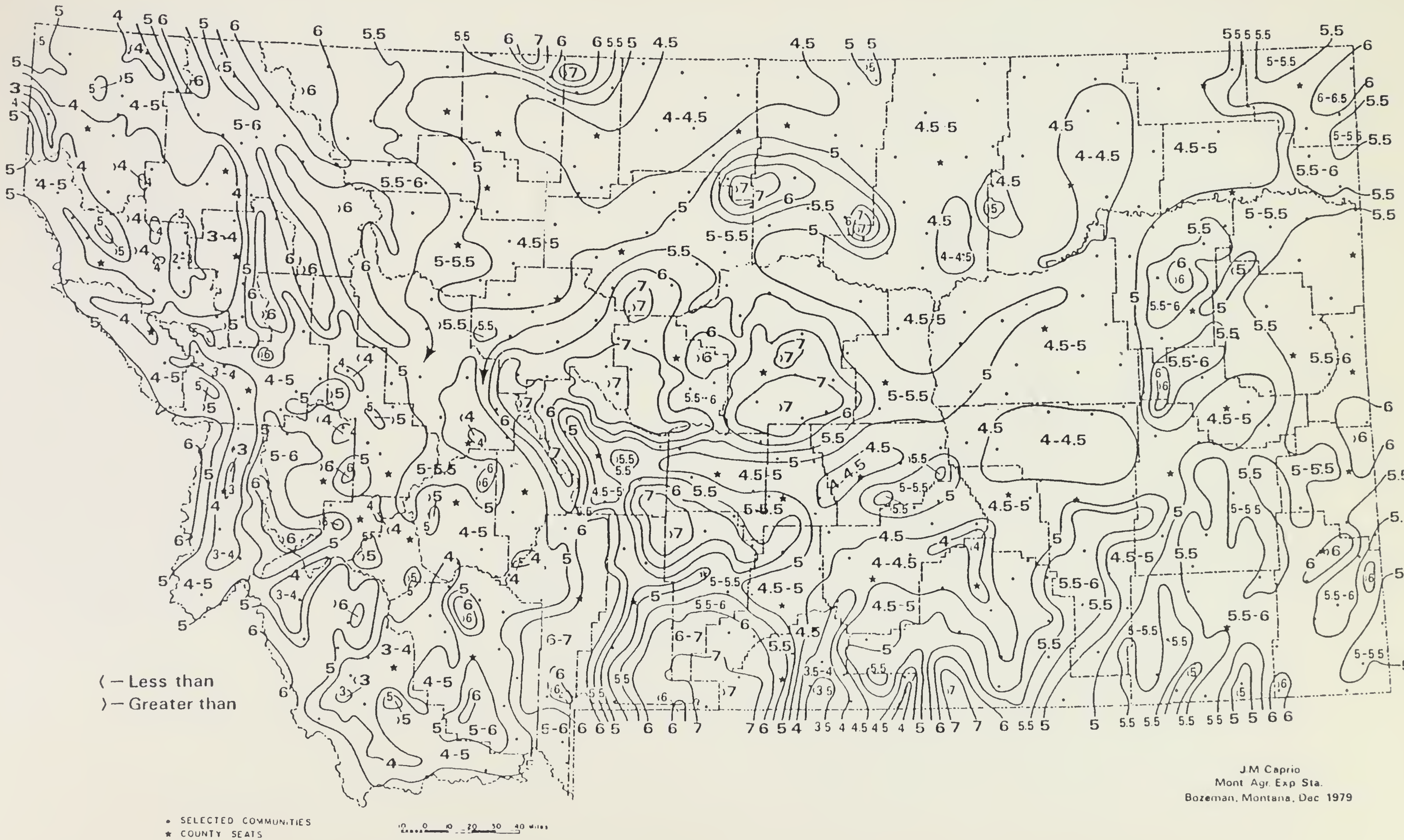
* Although the yield goal won't be reached the first year of establishment, it is figured in because of the inefficiency of phosphorus - tie up or turn around time is slow. Depending on the climatic factors, a response may not be indicative at first.

If the soil test indicates a P level of 8 ppm or less, then use the rates from the Legume-Irrigated Guide.

APPENDIX D

PRECIPITATION PROBABILITY MAP

Amount of Precipitation that is Equalled or Exceeded in 70 Percent of the Years
May 1 - July 31 (Inches)



APPENDIX E

CHARTIER AND JOHNSON SITES
CROP WATER USE WORKSHEETS

OFFICE WORKSHEET
TCD/MBMG CROP WATER USE
AND SOIL WATER MONITORING

OBSERVER TCD

LOCATION Chartier Site

CROP Alfalfa

PLANTING DATE May, 1983

EMERGENCE DATE

SOIL TYPE Ipano–Ticell complex, Big Timber–Castner Complex, loam silt loam, clay loam. Avg. depth 2'; rock frag. 20%, 2% O.M.

AWHC 1.8"/ft. = Total 3.6

MAXIMUM ROOTING DEPTH

	Month Day	Days Post Emergence	Time	Rain Fall (inches)	Effective Rainfall (inches)	Water Level in Pan (inches)	Change in Water Level in Pan (PET) (inches)	Total PET = PET Plus Effective Rainfall (inches)	Adjusted PET[1/] (Total PET x 0.65) (inches)	Crop Coeffici[2/]
1.	8/16	129	3:45 p.	.04	—	*				
2.	8/27	138	12:30 p	.06	—	*big pan 2.5"	5.5	5.56	3.61	.60
3.	9/2	144	10:30 a.	.65	.49	6.75	1.25	1.9	1.24	.60
4.	9/5	147	7:00 a.	0	C	6.9	1.1	1.1	.72	.60
5.	9/9	151	9:00 a.	.1	.08	7	1.0	1.1	.72	.60
6.	9/12	154	6:00	0	—	7.5	.5	.5	.33	.60
7.	9/16	158	12:00	0	—	7.25	.75	.75	.49	
8.	9/19	161	3:00	.2	.15	8.5	+ .5			
9.	9/23	165	6:00	0	C	6.5	1.5	1.5	.98	
10.	9/26	168	6:00	.1	.08	8.4	+ .4			
11.	10/4	175	6:00	0	—	7.5	.5	.5	.33	
12.	10/7	178	3:00	0	—	7.25	.75	.75	.49	
13.	10/10	181	6:00	0	—	7.25	.75	.75	.49	
14.	10/14	185	6:00	0	—	7.0	1.0	1.0	.65	
15.	10/25	196	4:30	.52	.39	8.25	+ .25			

$\Sigma = 4.94$

1/ Adjusted PET = Change in water level in pan x Kp, pan coefficient, to account for surrounding dryland conditions and wind.

2/ From Figure 2-10, Crop Coefficient Curves for Irrigated Crops in Montana.

WORKSHEET -- PAGE TWO

	Average 3/ Daily Crop Water Use (inches)	Accumulated Crop Water Use (inches)	Wkly.	% Field capacity	(3.6" Max.) Plant Avail. Soil Water (inches)	Avg. Daily	Accum. Crop Water use based on Feel+App.(in)	Wkly. Use	Notes
1.				5	0.18	0	7.62	0	Dormant (drought)
2.	.24	*		5	0.18	0	7.62	0	Dormant (drought)
3.	.12	*		8	0.29	.06	8.0	0.42	Dormant ; warm & windy
4.	.07			5	0.18	.02	8.11	.14	Dormant; Hot
5.	.07			5	0.18	0	8.11	0	Dormant; Cool
6.				18	0.65				
7.				15	0.54				
8.									
9.									
10.									
11.									
12.									
13.									
14.									
15.									

3/ Average Daily Crop Water Use = (Adjusted PET + Effective Rainfall) x Crop Coefficient.

OFFICE WORKSHEET
TCD/MBMG CROP WATER USE
AND SOIL WATER MONITORING

OBSERVER TCD

LOCATION Chartier Site

CROP Alfalfa

PLANTING DATE May, 1983

EMERGENCE DATE 4/9/84

SOIL TYPE Ipano-Ticell complex, Big Timber complex, loam, silt loam, clay loam. Avg. depth 2'; rock frag 20%, 2% O.M.

AWHC = 1.8"/ft. or 3.6" total

MAXIMUM ROOTING DEPTH

	Month Day	Days Post Emergence	Time	Rain Fall (inches)	Effective Rainfall (inches)	Water Level in Pan (inches)	Change in Water Level in Pan (PET) (inches)	Total PET = PET Plus Effective Rainfall (inches)	Adjusted PET 1/ (Total PET x 0.65) (inches)	Crop 2/ Coeffici[ent]
1.	5/4	25		--	--	----	----	----	----	---
2.	5/13	34	4:30 p	--	--	8.0	----	----	----	---
3.	5/19	40	12:00 p	.5	.38	7.0/8.0	1.0	1.5	.98	1
4.	5/27	48	12:00 p	0	0	6.25/8.0	1.75	1.75	1.14	1.05
5.	6/4	56	12:00 p	0.25	0.19	6.0/8.0	2.0	2.25	1.46	1.1
6.	6/12	64	1:45 p	1.8	1.35	8.8/8.0	+ 0.8	1.00	0.65	1.1
7.	6/18	70	8:30 a	0.18	0.14	7.25/8.0	0.75	0.93	0.60	1.1
8.	6/25	77	11:30 a	0.2	0.15	6.75/8.0	1.25	1.45	0.94	0.95*
9.	7/2	84	3:00 p	0.1	0.08	5.0/8.0	3.00	3.10	2.02	0.60
10.	7/8	90	1:30	0.02	--	6.5/8.0	1.5	1.52	.99	0.60
11.	7/16	98	12:45 p	0.02	--	4.75/8.0	3.25	3.27	2.13	0.60
12.	7/22	104	12:30 p	0	--	5.5/8.0	2.5	2.5	1.63	0.60
13.	7/28	110	3:30 p	0	--	4.5/8.0	3.5	3.5	2.28	0.60
14.	8/6	119	1:00 p	.12	.09	3.0/8.0	5.0	5.12	3.33	0.60
15.	8/10	123		.08	--	*				

Σ = 3.27

1/ Adjusted PET = Change in water level in pan x Kp, pan coefficient, to account for surrounding dryland conditions and wind.

2/ From Figure 2-10, Crop Coefficient Curves for Irrigated Crops in Montana.

*weighted, 5 days at 1.1; 2 days at 0.56, due to cutting

*Estimate see notes
.36 from pregrowing season precipitation
1.8 from Bauder est. of April use based on long term data

WORKSHEET -- PAGE TWO

	Average 3/ Daily Crop Water Use (inches)	Accumulated Crop Water Use (inches)	Wkly (daily x 7)	% Field capacity	(3.6 max) Plant Avail. Soil Water (inches)	Avg. daily	Accum. Crop Water use based on Feel+App. (in)	Wkly Use. + effective rainfall	Notes
1.	—	2.16*		90	3.24		2.16		Assumed accum. crop water used precip. plus soil at 100% before regrowth
2.	—	2.52		80	2.88		2.52		Note: also had rain which alfalfa used.
3.	0 .16	3.50	1.12	75	2.70	0.09	3.08	0.63	12 inches tall
4.	0.15	4.62	1.05	68	2.45	0.03	3.33	0.22	14 inches tall
5.	0.20	6.23	1.40	50	1.80	0.11	4.17	0.77	16–18 inches tall
6.	0.09	6.90	0.63	88	3.17	0	4.17	0	18" tall, cool, wet week (lower use) rainfall must have been more effective than 75% or evaporation from rain gauge.
7.	0.11	7.56	0.77	77	2.77	0.09	4.71	0.63	2 feet tall
8.	0.13	8.45	0.91	55	1.98	0.13	5.65	0.91	Cut on June 23
9.	0.17	9.65	1.19	48	1.73	0.05	5.98	0.35	5 inches tall, hot & windy; See Note #6
10.	0.10	10.24	.7	27	0.97	0.13	6.74	0.91	5 inches tall, hot & windy
11.	0.16	11.91	1.12	15	0.54	0.05	7.17	0.35	5.5 inches tall, hot & windy
12.	0.16	12.89	1.12	12	0.43	.02	7.28	0.14	5.5 inches tall, hot & windy
13.	0.23	14.26	1.61	5	0.18	.04	7.53	0.28	5.5 inches tall, hot & windy; Dormant
14.	0.22	16.26	1.54	5	0.18	0	7.62	0	5.5 inches tall, hot & windy; Dormant
15.				5	0.18	0	7.62	0	5.5 inches tall, hot & windy; Dormant

3/ Average Daily Crop Water Use = (Adjusted PET + Effective Rainfall) x Crop Coefficient.

TCD/MBMG CROP WATER USE
AND SOIL WATER MONITORING

OBSERVER TCD
LOCATION Chartier Site
CROP Barley
PLANTING DATE
EMERGENCE DATE

SOIL TYPE Loam, silt loam, 20% rock fragments, 2' to bedrock, 2% Organic matter
Max. AWHC = 1.8"/ft. or 3.6" total
MAXIMUM ROOTING DEPTH 4

	Month Day	Days Post Emergence	Time	Rain Fall (inches)	Effective Rainfall (inches)	Water Level in Pan (inches)	Change in Water Level in Pan (PET) (inches)	Total PET = PET Plus Effective Rainfall (inches)	Adjusted PET 1/ (Total PET x 0.65) (inches)	Crop 2/ Coefficient
1.	5/4	3	—	—	—	—	—	—	—	—
2.	5/13	12	—		—	8.0	—	—	—	—
3.	5/19	18	12:00 p	.5	.38	7.0/8.0	1.0	1.5	.98	0.55
4.	5/27	26	12:00 p	0	0	6.25/8.0	1.75	1.75	1.14	0.76
5.	6/4	34	12:00 p	0.25	0.19	6.0/8.0	2.0	2.25	1.46	0.84
6.	6/12	42	1:45 p	1.8	1.35	8.8/8.0	+ 0.8			0.86
7.	6/18	48	8:30 a	0.18	0.14	7.25/8.0	0.75	0.93	0.60	0.95
8.	6/25	55	11:30 a	0.2	0.15	6.75/8.0	1.25	1.45	0.94	1.0
9.	7/2	62	3:00 a	0.1	0.08	5.0/8.0	3.0	3.10	2.02	1.02
10.	7/8	69	1:30 p	0.02	—	6.5/8.0	1.5	1.52	.99	1.0
11.	7/16	77	12:45	0.02	—	4.75/8.0	3.25	3.27	2.13	0.8
12.	7/22	83	12:30	0	—	5.5/8.0	2.5	2.5	1.63	.75
13.	7/28	89	3:30	0	—	4.5/8.0	3.5	3.5	2.28	.5
14.	8/6	98	1:00	.12	.09	3.0/8.0	5.0	5.12	3.33	.5
15.	8/10	102	1:15	.08	—	*				

1/ Adjusted PET = Change in water level in pan x Kp, pan coefficient, to account for surrounding dryland conditions and wind.

2/ From Figure 2-10, Crop Coefficient Curves for Irrigated Crops in Montana.

WORKSHEET -- PAGE TWO

	Average[3/] Daily Crop Water Use (inches)	Accumulated Crop Water Use (inches)	Weekly	% Field capacity	(3,6 max) Plant Soil (inches)	Avg. daily Avail. Water	Accum. Water based on Feel+App. (in)	Wkly Use. Crop use	Notes
1.	—	—	—	100	3.6		0		
2.	—	—	—	100	3.6		0		May have used precip.
3.	.09	.54	.63	95	3.42		0.56	0.63	3 leaf
4.	0.11	1.35	0.77	90	3.24	0.02	0.74	0.14	4 leaf
5.	0.15	2.58	1.05	80	2.88	0.05	1.1	0.35	4 leaf, tillering
6.	0.18	4.05	1.26	97	3.49	0.09	1.84	0.63	6 leaf; see report Note #3, 0.18" leached below roots
7.	0.10	3.11	0.70	86	3.10	0.09	2.19	0.63	Stage 8 (jointing)
8.	0.13	4.05	0.91	63	2.27	0.14	3.17	0.98	Boot
9.	0.34	6.11	2.38	52	1.87	0.07	3.65	0.49	Heading
0.	0.12	7.10	.98	30	1.08	0.13	4.44	0.91	Headed
1.	0.21	8.83	1.47	18	0.65	0.05	4.87	0.35	Soft to hard dough
2.	0.20	10.02	1.40	15	0.54	0.02	4.98	0.14	Hard dough
3.	0.19	11.16	1.33	10	0.36	0.03	5.16	0.21	11.4 Ripe – straw dead
4.	0.15	12.83	1.05	8	0.29	0.04	5.66	0.28	11.4 Ripe – straw dead
5.				5	0.18	0.03	5.77	0.21	Harvested 8/7 – 8/9 *See Note #7

3/ Average Daily Crop Water Use = (Adjusted PET + Effective Rainfall) x Crop Coefficient.

OFFICE WORKSHEET
TCD/MBMG CROP WATER USE
AND SOIL WATER MONITORING

OBSERVER TCD

LOCATION Chartier Site

CROP Barley

PLANTING DATE

EMERGENCE DATE

SOIL TYPE Loam, silt loam; 20% rock fragments, 2' bedrock, 2% organic matter

Max. AWHC = 1.8"/ft. = 3.6" total

MAXIMUM ROOTING DEPTH 4

	Month Day	Days Post Emergence	Time	Rain Fall (inches)	Effective Rainfall (inches)	Water Level in Pan (inches)	Change in Water Level in Pan (PET) (inches)	Total PET = PET Plus Effective Rainfall (inches)	Adjusted PET[1/] (Total PET x 0.65) (inches)	Crop [2/] Coeffici
1.	8/16	108	3:45	.04	—	*				
2.	8/29	117	12:30	.06	—	*big pan 2.5	5.5	5.56	3.61	—
3.	9/2	120	10:00	.65	.49	6.75	1.25	1.9	1.25	—
4.	9/5	123	7:00	0	—	6.9	1.1	1.1	.72	—
5.	9/9	127	9:00	.1	.08	7	1.0	1.1	.72	—
6.	9/12	130	6:00	0	—	7.5	.5	.5	.33	
7.	9/16	134	12:00	0	—	7.25	.75	.75	.49	
8.	9/19	137	6:00	0	—	6.5	1.5	1.5	.98	
9.	9/23	141	3:00	.2	.15	8.5	+ .5			
10.	9/26	144	6:00	.1	.08	8.4	+ .4			
11.	10/4	151	6:00	0	—	7.5	.5	.5	.33	
12.	10/7	154	3:00	0	—	7.25	.75	.75	.49	
13.	10/10	157	7:00	0	—	7.25	.75	.75	.49	
14.	10/14	161	10:00	0	—	7.0	1.0	1.0	.65	
15.	10/25	172	4:30	.52	.39	8.25				

1/ Adjusted PET = Change in water level in pan x Kp, pan coefficient, to account for surrounding dryland conditions and wind.

2/ From Figure 2-10, Crop Coefficient Curves for Irrigated Crops in Montana.

	Average 3/ Daily Crop Water Use (inches)	Accumulated Crop Water Use (inches)	% Field capacity	(3.6 max.) Plant Avail. Soil Water (inches)	Avg. daily	Accum. Crop Water use based on Feel+App. (in)	Wkly. Use.	Notes
1.			5	0.18	0	5.77	0	Harvested
2.			5	0.18	0	5.77	0	Harvested
3.			10	0.36				Harvested
4.			5	0.18	0			Harvested
5.			20					
6.			18					
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								

3/ Average Daily Crop Water Use = (Adjusted PET + Effective Rainfall) x Crop Coefficient.

OFFICE WORKSHEET
TCD/MBMG CROP WATER USE
AND SOIL WATER MONITORING

OBSERVER TCD

LOCATION Johnson Site

CROP Winter Wheat

PLANTING DATE Fall, 1983

Regrowth XXXXXXXX DATE May 1

SOIL TYPE Darret-Castner Complex, 2% Organic Matter
10% R.F., 28" deep

AWHC = 4.89"; 2.09"/ft.

MAXIMUM ROOTING DEPTH 4

	Month Day	Days Post Emergence	Time	Rain Fall (inches)	Effective Rainfall (inches)	Water Level in Pan (inches)	Change in Water Level in Pan (PET) (inches)	Total PET = PET Plus Effective Rainfall (inches)	Adjusted PET1/ (Total PET x 0.65) (inches)	Crop 2/ Coeffici[illegible]
1.	5/4	3	--	—	—	—	—	—	—	—
2.	5/13	12				8.0				
3.	5/19	18	2:30	0.4	0.3	6.5/8"	1.5	1.9	1.24	0.6
4.	5/27	26	2:00	0.2	0.15	6.0/8.0	2.0	2.15	1.40	0.84
5.	6/4	34	2:00	0.1	0.08	5.25/8.0	2.75	2.85	1.85	0.9
6.	6/12	42	3:00	2.25	1.69	9.25/8.0	+ 1.25	1.00	0.65	1.02
7.	6/18	48	10:00	0.12	0.09	7.0/8.0	1.0	1.12	0.73	1.05
8.	6/25	56	1:30 p	0.3	0.23	6.5/8.0	1.5	1.80	1.17	1.05
9.	7/2	63	5:00	0.12	0.09	5/8.0	3.0	3.12	2.01	1.00
10.	7/8	69	3:30	0.04	—	5.75/8	2.25	2.29	1.49	0.9
11.	7/16	77	3:00	.06	—	4.75/8	3.25	3.31	2.15	.55
12.	7/22	83	2:15	0	—	5.5/8	2.5	2.5	1.63	0
13.										
14.	8/6	98	2:15	.05						
15.	8/10	102	2:45	0						

$\Sigma = 3.64$

1/ Adjusted PET = Change in water level in pan x Kp, pan coefficient, to account for surrounding dryland conditions and wind.

2/ From Figure 2-10, Crop Coefficient Curves for Irrigated Crops in Montana.

*estimated
.24 from stored soil moisture
1.0 inch in April from Bauder

WORKSHEET — PAGE TWO

	Average[3/] Daily Crop Water Use (inches)	Accumulated Crop Water Use (inches)	Wkly.	% Field capacity	4.89 max. Plant Avail. Soil Water (inches)	Avg. Daily	Accum. Water based Feel+App. (in) + eff. rain	Crop use on wkly.	Notes
1.	—	1.24*		95	4.65		1.24	*	
2.	—	1.49		90	4.40		1.49		
3.	.19	2.23	1.33	80	3.91		2.28	0.91	5 leaf
4.	0.15	3.37	1.05	75	3.67	0.05	2.67	0.35	6 leaf – jointing
5.	0.21	5.04	1.47	50	2.45	0.16	3.97	1.12	boot/heading
6.	0.08	5.69	0.56	90	4.40	0	3.97	0	See Report Notes #4 About F/A Results
7.	0.13	6.45	0.91	78	3.81	0.11	4.65	0.77	Flowering
8.	0.18	7.68	1.26	62	3.03	0.14	5.66	0.98	
9.	0.29	9.69	2.03	54	2.64	0.07	6.14	0.49	Headed
10.	0.22	11.03	1.54	30	1.48	0.19	7.3	1.33	
11.	0.15	12.21	1.05	20	.98	0.06	7.8	.42	11.3
12.	0	12.21	0	15	.73	0.04	8.05	.28	11.4 Straw Dead
13.									
14.									
15.									

3/ Average Daily Crop Water Use = (Adjusted PET + Effective Rainfall) x Crop Coefficient.

OFFICE WORKSHEET
TCD/MBMG CROP WATER USE
AND SOIL WATER MONITORING

OBSERVER TCD

LOCATION Johnson Site

CROP Spring grains (barley)

PLANTING DATE

EMERGENCE DATE

SOIL TYPE Farret-Castner Complex, 2% O.M., 10% rock fragments, 28" deep soil

AWHC = 4.89; 2.09"/ft

MAXIMUM ROOTING DEPTH 4

	Month Day	Days Post Emergence	Time	Rain Fall (inches)	Effective Rainfall (inches)	Water Level in Pan (inches)	Change in Water Level in Pan (PET) (inches)	Total PET = PET Plus Rainfall (inches)	Adjusted PET1/ (Total PET x 0.65) (inches)	Crop Coeffic
1.	5/13	0	—	—	—	8.0	—	—	—	—
2.	5/19	3	2:30 p	.4	0.3	6.5/8"	1.5	1.9	1.24	.1
3.	5/27	11	2:00	.2	0.15	6.0/8.0	2.0	2.2	1.43	.35
4.	6/4	19	2:00	.1	0.08	5.25/8.0	2.75	2.85	1.85	.64
5.	6/12	27	3:00	2.25	1.69	9.25/8.0	+ 1.25	1.00	0.65	.80
6.	6/8	33	10:00	0.12	0.09	7/8.0	1.00	1.12	0.73	.88
7.	6/25	40	1:30 p	0.3	0.23	6.5/8.0	1.50	1.8	1.17	1.0
8.	7/2	47	5:00	0.12	0.09	5/8.0	3.0	3.12	2.03	1.02
9.	7/8	53	3:30	0.04	—	5.75/8	2.25	2.29	1.49	1.05
10.	7/6	61	3:00	0.06	—	4.75/8	3.25	3.31	2.15	1.02
11.	7/22	67	2.15	00	—	5.5/8	2.5	2.5	1.63	.95
12.	7/28	73	4:45	0	—	5.8/8	2.2	2.2	1.43	.92
13.	8/6	82	2:15	.05	—	5.25/8	2.75	2.75	1.79	.78
14.	8/10	86	2:45	0		6.25/8	1.75	1.75	1.14	.62
15.										

1/ Adjusted PET = Change in water level in pan x Kp, pan coefficient, to account for surrounding dryland conditions and wind.

2/ From Figure 2-10, Crop Coefficient Curves for Irrigated Crops in Montana.

	Average[3/] Daily Crop Water Use (inches)	Accumulated Crop Water Use (inches)	Wkly.	% Field capacity	4.89 Max. Plant Avail. Soil Water (inches)	Avg. Daily	Accum. Water based on Feel+App.	Crop use (in) + eff. rain Wkly.	Notes
1.	—	—		100	4.89		0		
2.	0.04	0.12	0.12	90	4.40		0.49	0.57	% field capacity low or evap. from surface or weeds; 1 leaf
3.	0.06	0.62	0.42	85	4.16	0.05	0.88	0.35	3 leaf
4.	0.15	1.79	1.05	80	3.91	0.04	1.21	0.28	3 leaf tillering
5.	0.07	2.31	0.49	98	4.79	0.07	1.77	0.49	5 leaf See Report Note #5
6.	0.11	2.95	0.77	84	4.11	0.13	2.54	0.91	Jointing
7.	0.17	4.12	1.19	73	3.57	0.11	3.31	0.77	Jointing, no boot yet
8.	.30	6.19	2.10	65	3.19	0.07	3.78	0.49	
9.	0.26	7.73	1.82	52	2.54	0.11	4.43	0.77	Heading
10.	0.27	9.92	1.89	30	1.47	.13	5.50	.91	Milk
11.	0.26	11.47	1.82	22	1.08	0.07	5.89	0.49	Milky Ripe
12.	0.22	12.79	1.54	13	0.64	0.07	6.33	0.49	Mealy Ripe
13.	0.16	14.19	1.12	10	0.49	0.02	6.48	0.14	11.3 Hard Dough
14.	0.18	14.90	1.26	8	0.39	0.03	6.58	0.21	11.4 Tried to Cut
15.									

3/ Average Daily Crop Water Use = (Adjusted PET + Effective Rainfall) x Crop Coefficient.

APPENDIX F

CROP COEFFICIENT CURVES

Figure 10: Crop Coefficient Curve for Spring Wheat and Barley

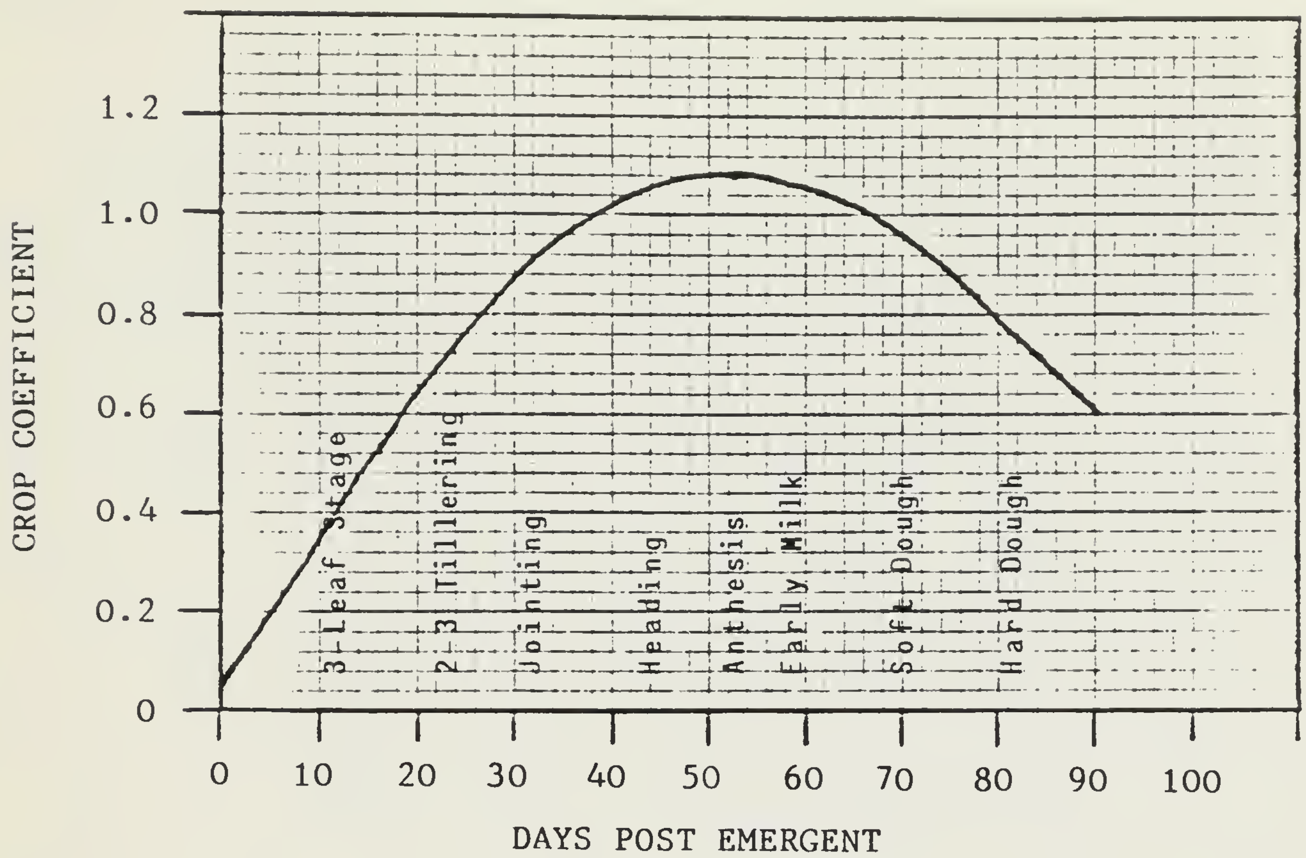
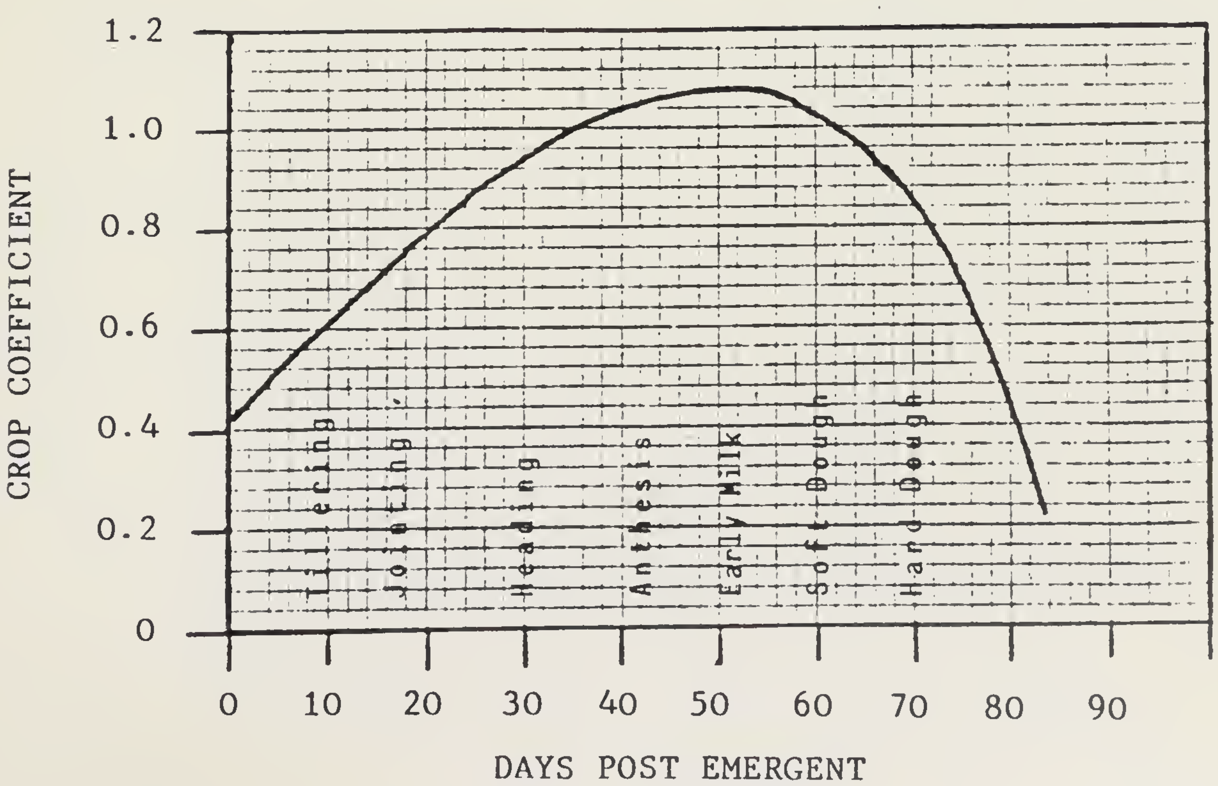
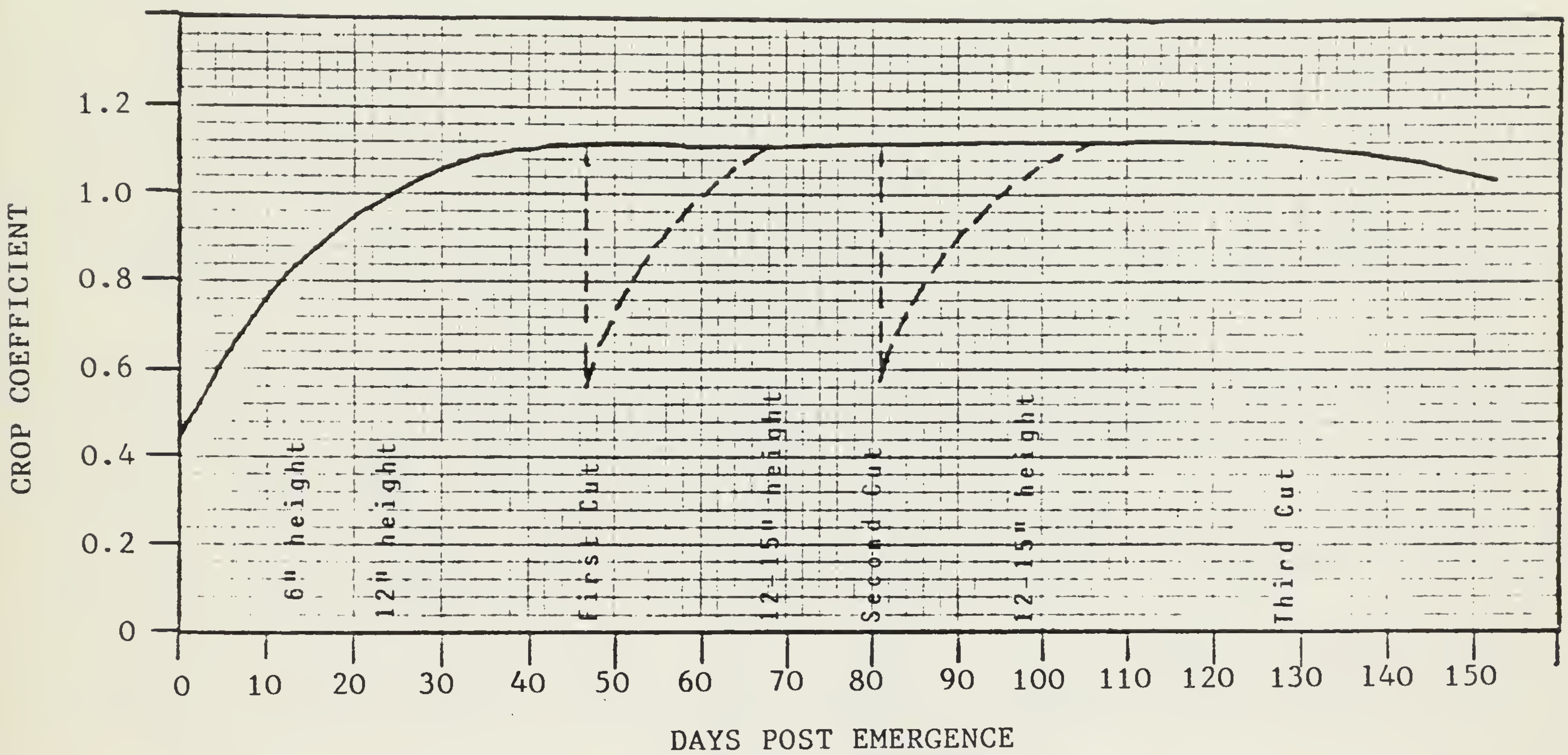


Figure 11: Crop Coefficient Curve for Winter Wheat



From: Scheduling Irrigation with Evaporation Pans. Cooperative Extension Service. Montana State University, Bozeman, Bulletin 1262.

Figure 12: Crop Coefficient Curve for Alfalfa



From: Scheduling Irrigation with Evaporation Pans. Cooperative Extension Service, Montana State University, Bozeman, Bulletin 1262

FIELD SCOUT RESPONSIBILITIES

1. Twice weekly, measure water in both evaporation pans on the Chartier site. Record them separately. Record rain gauge reading. After major precipitation events ($\geq$ .5" ppt.) the pans and rain gauge should be read within 24 hours.

   The evaporation pan water levels should be maintained at the 8 inch mark, either by adding water or baling it out. MAKE SURE THE WATER LEVEL IS RECORDED FIRST!

   The same applies for the Johnson site, except there is only one evaporation pan to measure.

   Keep evaporation pans and rain gauges free from insects, soil and other miscellaneous foreign materials that may effect the readings.

   IF: The rain gauge is emptied for one reason or another, refill to the 1/8" mark with water and another 3/8" of mineral oil, so that the combination of water and oil fills the gauge to the 1/2" mark.

2. At both sites measure the stored soil moisture with the Paul Brown Soil Moisture Probe, Sharp Shooter (shovel) or hand auger. At each foot increment to a restricting layer, estimate the soil moisture content by the "Feel and Appearance" method, based on the chart.

3. Measure designated shallow ground water wells once a month and 24 hours after any major precipitation event.

4. Record maximum and minimum temperatures daily when Chartiers are unable to record them. Also estimate percent cloud cover and any other local weather conditions.

5. Equipment and training will be provided on all of the above.

FIELD CREW RESPONSIBILITIES

1. Twice weekly, measure water in both evaporation pans on the Chartier site. Rec[illegible] them separately. Record rain gauge reading. After major precipitation event[illegible] (2-3" rain) the pans and rain gauge should be read within 24 hours.

   The evaporation pan water levels should be maintained at the 8 inch mark, eith[illegible] by adding water or bailing it out. Make sure the water level is recorded FIRST[illegible]

   The same applies for the Johnson site, except there is only one evaporation p[illegible] to measure.

   Keep evaporation pans and rain gauges free from insects, soil and other mat[illegible] (leaves, foreign materials) that may affect the readings.

   NB: The rain gauge is emptied for each reading as written, refill to the 1/8" m[illegible] with water and another 1/8" of mineral oil, so that the combination of wat[illegible] and oil fills the gauge to the 1/4" mark.

2. At both sites measure the stored soil moisture with the [illegible] Probe, [illegible] or hand auger. At each [illegible] time [illegible], calibrate the soil moisture content in the "Wet and Dry" [illegible] percent: Mark on the sheet.

3. Measure [illegible] and ground water wells once a month and 24 hours after a major precipitation event.

4. Record maximum and minimum temperatures daily when there are any people on[illegible] [illegible], percent cloud cover and any other local weather condi[illegible]

5. Equipment and training will be provided on all of the above.

APPENDIX IB

1985 ANNUAL REPORT

STOCKETT-SAND COULEE

CROP WATER USE ESTIMATES

MONTANA SALINITY CONTROL ASSOCIATION

1985 ANNUAL REPORT
STOCKETT-SAND COULEE

CROP WATER USE ESTIMATES

The 1985 drought meant minimal crop water use for most of the growing season. However, more rainfall occurred in August and September than during the previous four months. This resulted in a high potential for deep percolation of soil water at the end of the season, despite crop failures due to drought. This report will present and discuss crop water use estimates for the 1985 season, and relative differences in deep drainage potential between areas in fallow, small grains, and an alfalfa-grass mixture.

METHODS

Water use (ET) was estimated on six fields in the Stockett-Sand Coulee area. Included were fallow fields at both the Chartier and Johnson farms, two stands of a Ladak 65 alfalfa-intermediate wheatgrass mixture at the Chartier farm (a first and a second year stand), a barley field (Johnson farm), and a winter wheat field (Chartier farm).

Three methods of estimating crop water use were employed. The coefficient method, based on pan evaporation, was modified somewhat over last year in an attempt to account for dryland rather than irrigated conditions. In this method, potential (pan) evaporation is multiplied by two coefficients between 0 and 1 to account for the varying effects of the crop grown, its growth stage, and soil moisture on actual evapotranspiration (ET). Although this modification may have improved the method, it still appears to overestimate crop water use. The results of this method are presented in this report, although they are probably of little value. Use of this method may be discontinued this year, since conversion of potential evaporation to ET without expensive monitoring of weather conditions is tenuous. Also, methods described below appear to be more accurate.

Another possibility for estimating seasonal crop water use is to take known relationships between water use and yield (developed for various crops through research), and solve the relationships for water use when yields are known. This method would tend to underestimate water use when yield is reduced by poor timing of rainfall, poor fertility, weeds, diseases, insects, or other management factors. This method could not be used for 1985, since crop failures meant no yields to measure, except for barley (6.7 bu/ac). Past research in the northern Great Plains has shown that nine inches of crop water use is required to produce profitable small grain yields. We can deduce from this that total small grains water use was much less than nine inches for the marginal yields of 1985.

One difficulty to overcome before yield - water use relationships can be used in this study is the question of varietal differences, particularly with alfalfa. Water use efficiencies vary greatly amongst alfalfa varieties. We will determine if use of this method on the alfalfa - grass mixture is possible during the upcoming year.

The third method of estimating crop water use is the feel and appearance (F/A) method, in which soil water contents are estimated by the feel, appearance, and texture of the soil (see previous reports). This is done on a regular basis to estimate rates of ET. The F/A method appears to give the most reasonable estimates of water use. This is because a water budget approach is taken in this method; rainfall and pre-plant soil moisture are partitioned into ET, deep percolation, and soil storage components at regular intervals throughout the growing season. Therefore, most discussion in this report will focus on the F/A method.

Caution is advised in use of data presented in this report; results are still based on rough estimates, and not intended to be interpreted as actual measurements. The data only show relative differences in water use amongst

cropping treatments. The F/A method may also overestimate crop water use. For example, less than six inches of crop water use would be expected for a barley yield of 6.7 bu., rather than the 9.95 inches given by the F/A method. Seven inches of evaporation from fallow ground also seems high. These anomalies may be due to timing of precipitation events as well as inadequacies in the F/A method. We will attempt to refine and improve the F/A method this year by taking surface and subsurface moisture conditions into account.

DISCUSSION

Weekly estimates of average daily and cumulative ET are presented in graphical and tabular form for each field. Both the F/A and the coefficient method are presented, except for the fallow fields, where the coefficient method cannot be applied. Data for the most part are self explanatory, although a brief description of the cumulative water use graphs is in order. Cumulative precipitation is included in the graphs with cumulative water use estimates. This provides a picture of how stored soil moisture changes over the growing season. Where precipitation increases more rapidly than water use, a period of increased soil moisture is indicated. Moisture depletion occurs where water use increases but precipitation does not.

For the fields where cumulative precipitation exceeds cumulative water use (as estimated by the F/A method), there is potential for deep drainage. This occurred on both fallow sites, the new alfalfa-wheatgrass stand, and the barley site. Estimates of deep drainage were made by adding amounts of each precipitation event to stored soil moisture at that time. If the total was greater than the water holding capacity of the profile, the excess was assumed to deep percolate (see tables in the appendix). This calculation allows for no runoff or evaporation: all precipitation is assumed to infiltrate the soil. This would not be the case for high intensity rainfalls, where runoff may be significant. Also, no deep percolation was calculated for the second year alfalfa: its deeper roots were assumed to use this excess moisture. According

to the estimates, most deep percolation occurred after the heavy rains in early August. The highest estimates of total deep percolation were under fallow (3.95 and 3.20 inches), with some also occurring under the new alfalfa-wheatgrass stand (.52 inches), and under barley (.20 inches).

Water use budgets as estimated by the F/A method are summarized in table six. Total water use (ET) was greatest on the second year alfalfa-wheatgrass stand (11.64 in.), followed by barley (9.45 in.), the new alfalfa-wheatgrass (8.41 in.), and fallow (7.9 and 7.35 in.). The ordering is affected by differences in length of growing season; note that the new alfalfa-wheatgrass was not planted until late May. Winter wheat is not included because it was hailed out June 1, and then plowed under. The winter wheat would most resemble fallow ground after June 1.

SUMMARY

The soils under consideration here have a very limited water holding capacity. Despite the drought conditions of 1985, with the fall rains as much as 4.0 inches may have deep percolated under fallow, compared to half an inch or less under cropped areas. The estimates of stored soil moisture at the end of the growing season show that the fall rains were sufficient to fill the soil profiles. On any of this land fallowed next year, most precipitation will be lost to deep percolation, possibly recharging acid drainage below.

The unusual timing of last year's rainfall helps point out several factors relevant to abatement of soil water deep percolation. In order to be most effective, cropping strategies must provide for maximum crop water use and a prolonged growing season. The deep root system and long growing season of alfalfa and alfalfa-grass mixtures give this type system a clear advantage over other strategies such as flex cropping. Recropping small grains will certainly increase water use over a crop fallow system, but the limited growing season of spring grains makes timing of precipitation an important

consideration. In the northern Rocky Mountains, precipitation probabilities are highest near the beginning and the end of the growing season. Under small grain systems, most deep percolation probably occurs during these times, when there is no crop water use. With an established alfalfa stand, precipitation will be utilized beginning early in the season, and late into the fall. Therefore, perennial stands may offer the only opportunity for prevention of deep percolation throughout the growing season.

concentration. In the northern Great Mountains, precipitation greatest values are highest near the beginning and the end of the growing season. Under small grain systems, most deep percolation probably occurs during these times, when there is no crop water use. With an established alfalfa stand, precipitation will be utilized beginning early in the season, and late into the fall. Therefore, perennial stands may offer the only opportunity for prevention of deep percolation throughout the growing season.

TABLE I.

Average Daily and Cumulative Crop Water Use by Week

Chartier Site - Alfalfa-Wheatgrass (Second year stand)

Week	F/A Daily Average	F/A Cumulative	Co-efficient Daily Average	Co-efficient Cumulative
4/7 - 4/13	.08	.63	.08	.61
4/14 - 4/20	.10	1.36	.12	1.48
4/21 - 4/27	.07	1.83	.12	2.35
4/28 - 5/4	.12	2.67	.14	3.35
5/5 - 5/11	.04	2.95	.10	4.02
5/12 - 5/18	.06	3.37	.08	4.60
5/19 - 5/25	.07	3.83	.08	5.13
5/26 - 6/1	.06	4.27	.12	5.96
6/2 - 6/8	.06	4.72	.17	7.16
6/9 - 6/15	.11	5.51	.14	8.18
6/16 - 6/22	.04	5.80	.14	9.17
6/23 - 6/29	.05	6.14	.09	9.78
6/30 - 7/6	.04	6.40	.06	10.18
7/7 - 7/13	.07	6.88	.05	10.54
7/14 - 7/20	.03	7.08	.04	10.83
7/21 - 7/27	.03	7.27	.04	11.13
7/28 - 8/3	.04	7.55	.11	11.88
8/4 - 8/10	.08	8.14	.17	13.08
8/11 - 8/17	.07	8.64	.08	13.67
8/18 - 8/24	.09	9.26	.22	15.23
8/25 - 8/31	.04	9.56	.14	16.22
9/1 - 9/7	.08	10.15	.07	16.68
9/8 - 9/14	.10	10.84	.06	17.08
9/15 - 9/21	.06	11.25	.06	17.47
9/22 - 9/28	.03	11.47	.05	17.82
9/29 - 10/5	.01	11.53	.06	18.22
10/6 - 10/12	.01	11.59	.06	18.62
10/13 - 10/19	.007	11.64	.06	19.02

FIGURE I. Alfalfa-grass Chartier Site

Cumulative precipitation vs. crop water use estimates by coefficient and feel/appearance methods, beginning 4/7/85

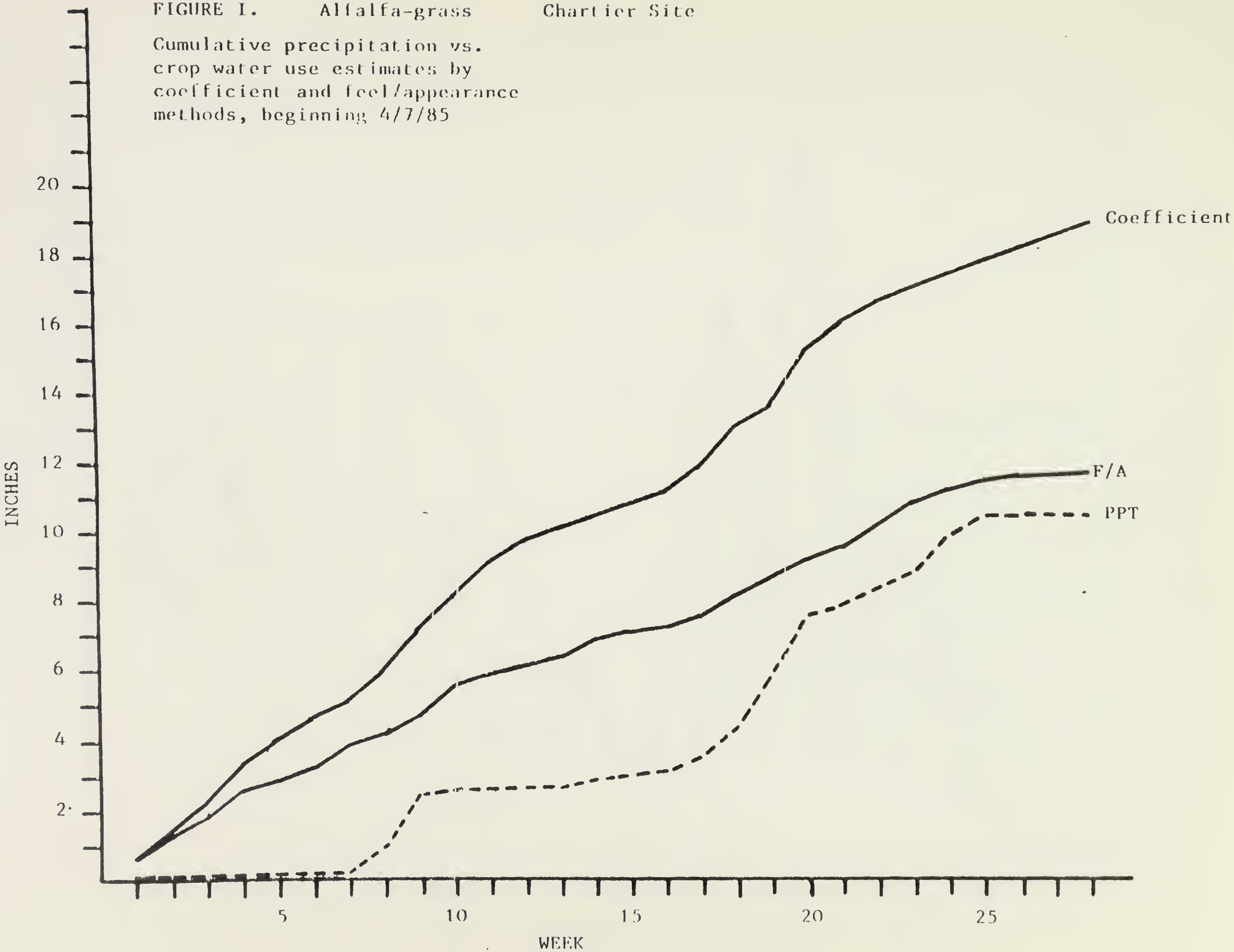


FIGURE 2. Alfalfa-grass Chartier Site

Avg. daily water use estimates
by coefficient and feel/appearance
methods beginning 4/7/85

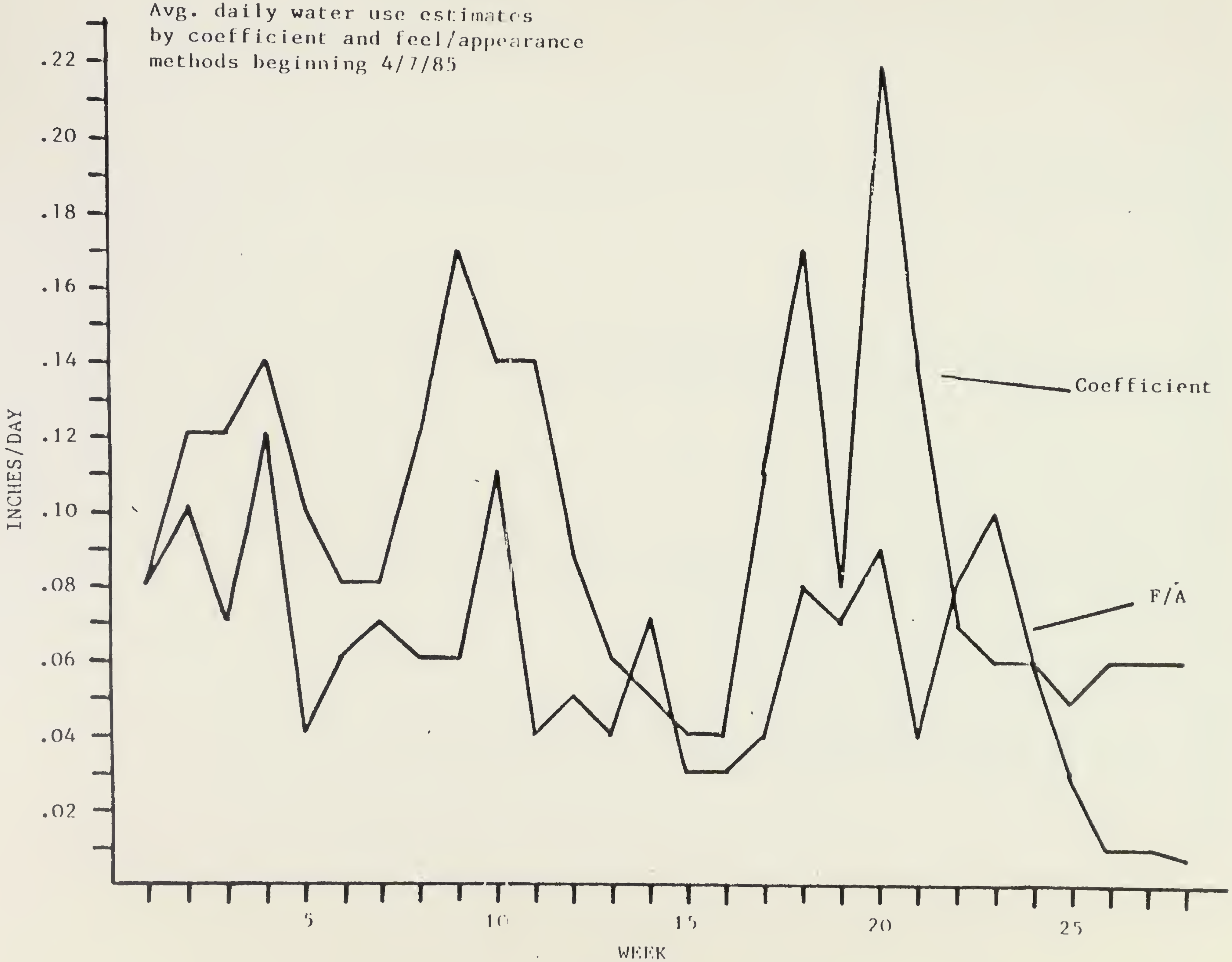


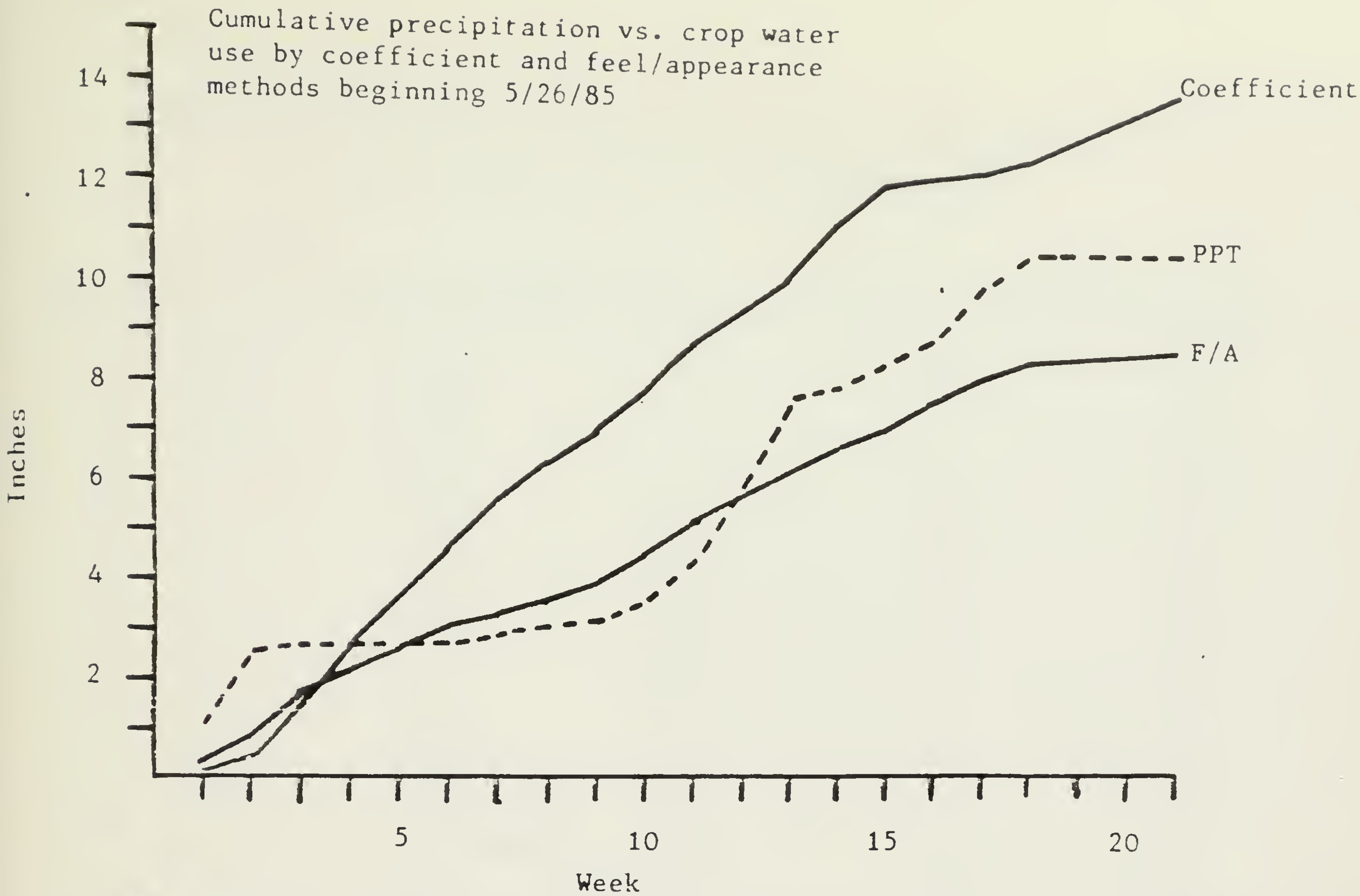
TABLE 11.

Average Daily and Cumulative Crop Water Use by Week

Chartier Site - New Alfalfa Wheatgrass

Week	F/A Daily Average	F/A Cumulative	Co-efficient Daily Average	Co-efficient Cumulative
5/19 - 5/25	Planting			
5/26 - 6/1	.04	.30	.01	.05
6/2 - 6/8	.08	.84	.06	.44
6/9 - 6/15	.12	1.68	.14	1.42
6/16 - 6/22	.07	2.15	.17	2.62
6/23 - 6/29	.06	2.57	.14	3.62
6/30 - 7/6	.07	3.03	.13	4.55
7/7 - 7/13	.03	3.27	.15	5.57
7/14 - 7/20	.04	3.56	.11	6.32
7/21 - 7/27	.05	3.88	.09	6.93
7/28 - 8/3	.08	4.47	.11	7.69
8/4 - 8/10	.09	5.08	.15	8.71
8/11 - 8/17	.07	5.56	.08	9.29
8/18 - 8/24	.07	6.08	.10	9.97
8/25 - 8/31	.06	6.53	.16	11.06
9/1 - 9/7	.06	6.94	.11	11.80
9/8 - 9/14	.08	7.47	.02	11.96
9/15 - 9/21	.07	7.96	.01	12.01
9/22 - 9/28	.04	8.23	.04	12.26
9/29 - 10/5	.01	8.29	.06	12.68
10/6 - 10/12	.01	8.35	.06	13.10
10/13 - 10/19	.01	8.40	.06	13.52

FIGURE 3. New Alfalfa - Chartier Site



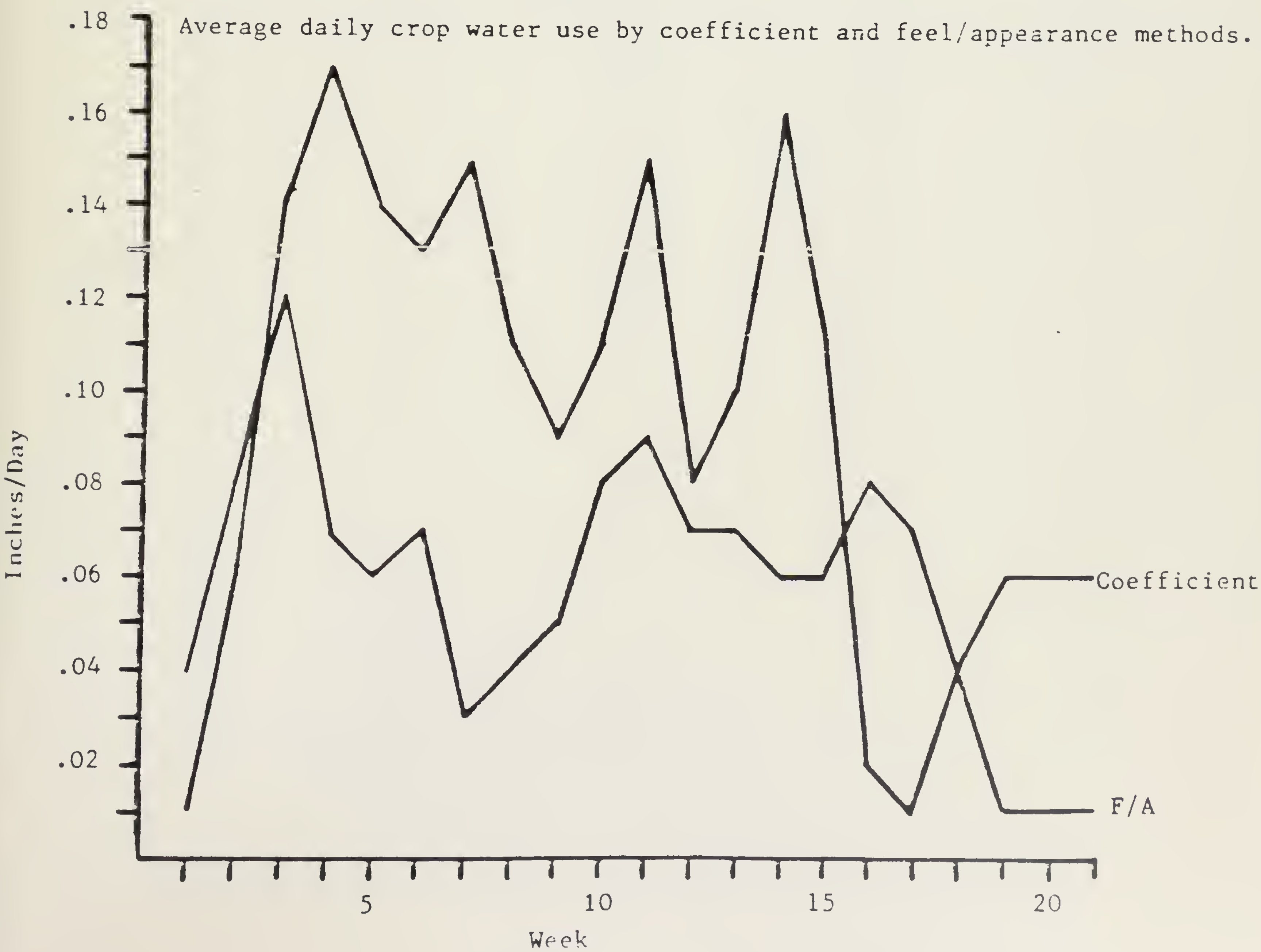


TABLE III.

Average Daily and Cumulative Evaporation Losses from Fallow Ground as Estimated by Feel and Appearance Method

Week	Chartier Daily Average	Chartier Cumulative	Johnson Daily Average	Johnson Cumulative
4/7 - 4/13	---	---	---	---
4/14 - 4/20	.06	.44	.05	.34
4/21 - 4/27	.04	.73	.04	.63
4/28 - 5/4	.04	1.02	.04	.92
5/5 - 5/11	.05	1.35	.06	1.32
5/12 - 5/18	.04	1.60	.04	1.60
5/19 - 5/25	.04	1.88	.07	2.12
5/26 - 6/1	.04	2.16	.08	2.70
6/2 - 6/8	.04	2.46	.06	3.11
6/9 - 6/15	.05	2.84	.05	3.46
6/16 - 6/22	.06 (plowed)	3.26	.04	3.74
6/23 - 6/29	.05	3.58	.04	4.03
6/30 - 7/6	.05	3.90	.05	4.35
7/7 - 7/13	.04	4.17	.03	4.59
7/14 - 7/20	.03	4.35	.03	4.77
7/21 - 7/27	.04	4.66	.04	5.03
7/28 - 8/3	.05	5.01	.05	5.41
8/4 - 8/10	.05	5.38	.04	5.72
8/11 - 8/17	.05	5.74	.05	6.08
8/18 - 8/24	.05	6.10	.06	6.49
8/25 - 8/31	.04	6.35	.04	6.77
9/1 - 9/7	.02	6.51	.03	6.99
9/8 - 9/14	.03	6.69	.04	7.28
9/15 - 9/21	.02	6.85	.03	7.49
9/22 - 9/28	.02	6.99	.02	7.64
9/29 - 10/5	.02	7.11	.01	7.73
10/6 - 10/12	.02	7.23	.01	7.81
10/13 - 10/19	.02	7.35	.01	7.90

FIGURE 4. Fallow Chartier Site

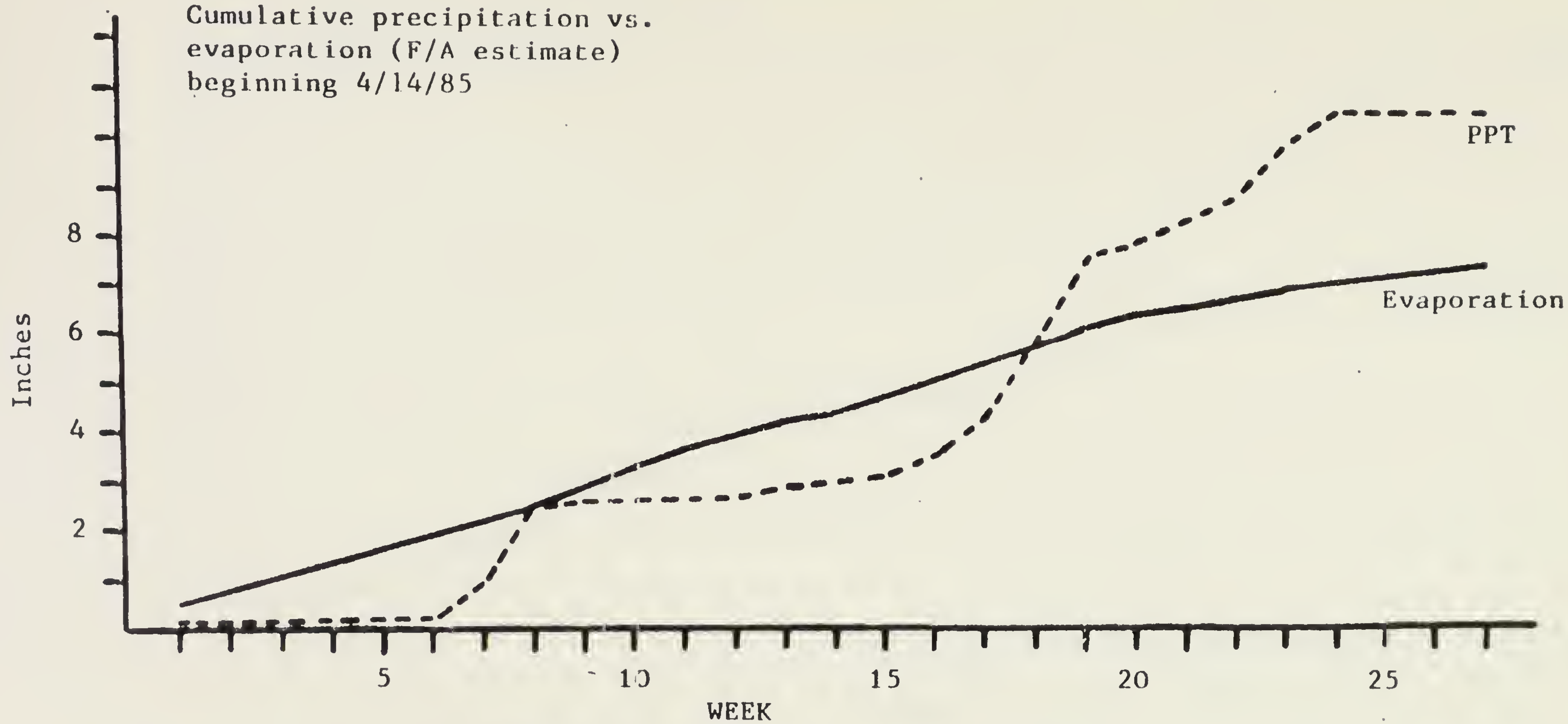


FIGURE 5. Fallow Johnson Site

Cumulative precipitation vs. evaporation (F/A estimate) beginning 4/14/85

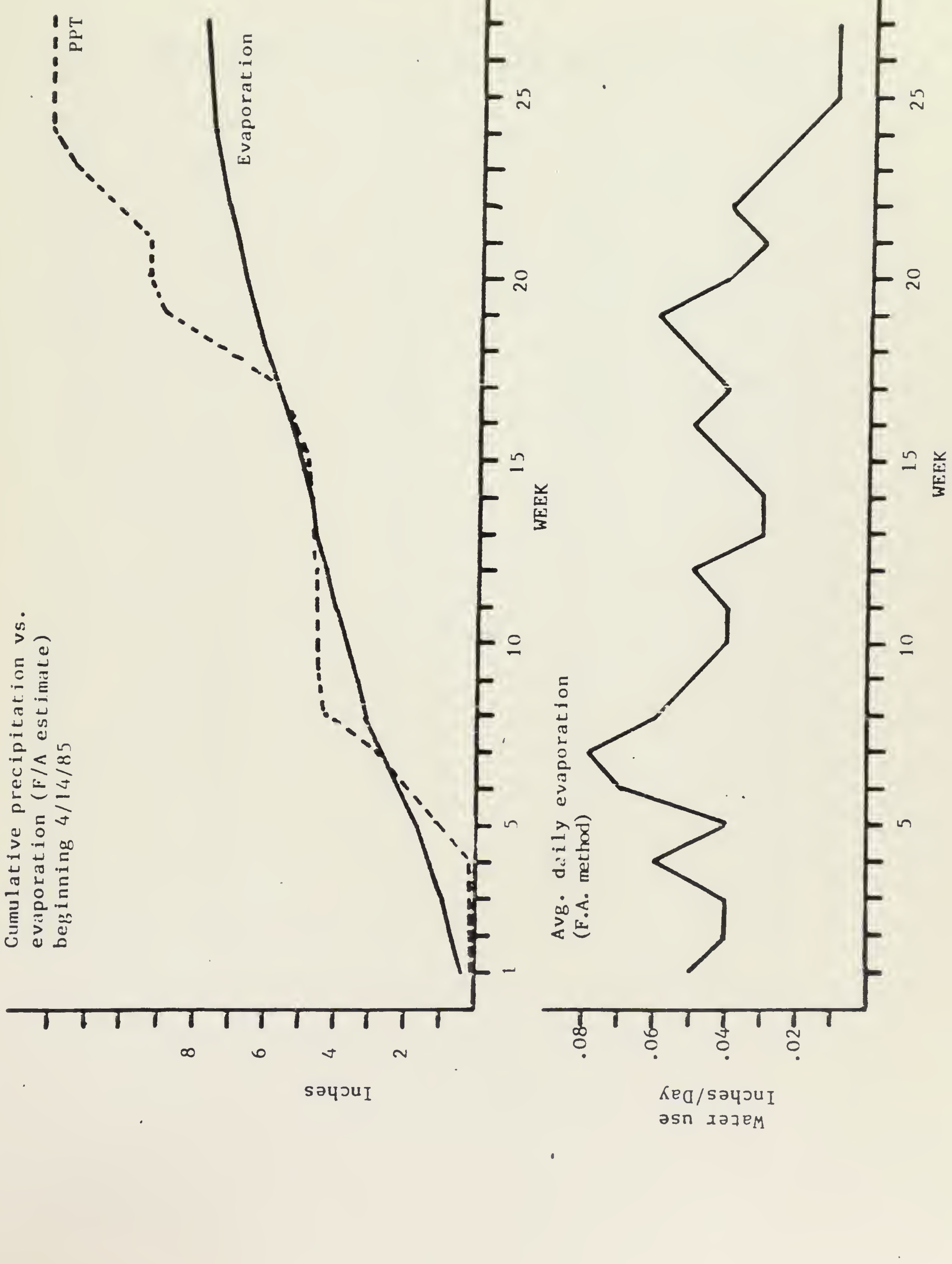


TABLE IV.

Estimates of
Crop Water Use - Barley (Johnson Site)

Week	F/A Daily Average	F/A Cumulative	Co-efficient Daily Average	Co-efficient Cumulative
5/5 - 5/11	.10	.69	.03	.20
5/12 - 5/18	.06	1.09	.07	.69
5/19 - 5/25	.08	1.66	.18	1.97
5/26 - 6/1	.11	2.46	.15	3.04
6/2 - 6/8	.13	3.40	.15	4.07
6/9 - 6/15	.09	4.01	.21	5.57
6/16 - 6/22	.08	4.58	.20	6.99
6/23 - 6/29	.08	5.16	.17	8.15
6/30 - 7/6	.09	5.78	.16	9.24
7/7 - 7/13	.07	6.28	.12	10.09
7/14 - 7/20	.05	6.66	.07	10.60
7/21 - 7/27	.04	6.97	.06	11.02
7/28 - 8/3	.05	7.31	.06	11.45
8/4 - 8/10	.08	7.86	.09	12.08
8/11 - 8/17	.08	8.40	.07	12.60
8/18 - 8/24	.07	8.90 (plowed)	.05	12.92
8/25 - 8/31	.03	9.12	.02	13.07
9/1 - 9/7	.03	9.36	0	13.07
9/8 - 9/14	.03	9.57	0	13.07
9/15 - 9/21	.01	9.66	0	13.07
9/22 - 9/28	.01	9.73	0	13.07
9/29 - 10/5	.01	9.80	0	13.07
10/6 - 10/12	.01	9.88	0	13.07
10/13 - 10/19	.01	9.95	0	13.07

FIGURE 6. Barley - Johnson Site

Cumulative precipitation and crop water use estimated by coefficient and feel/appearance methods beginning 5/5/85

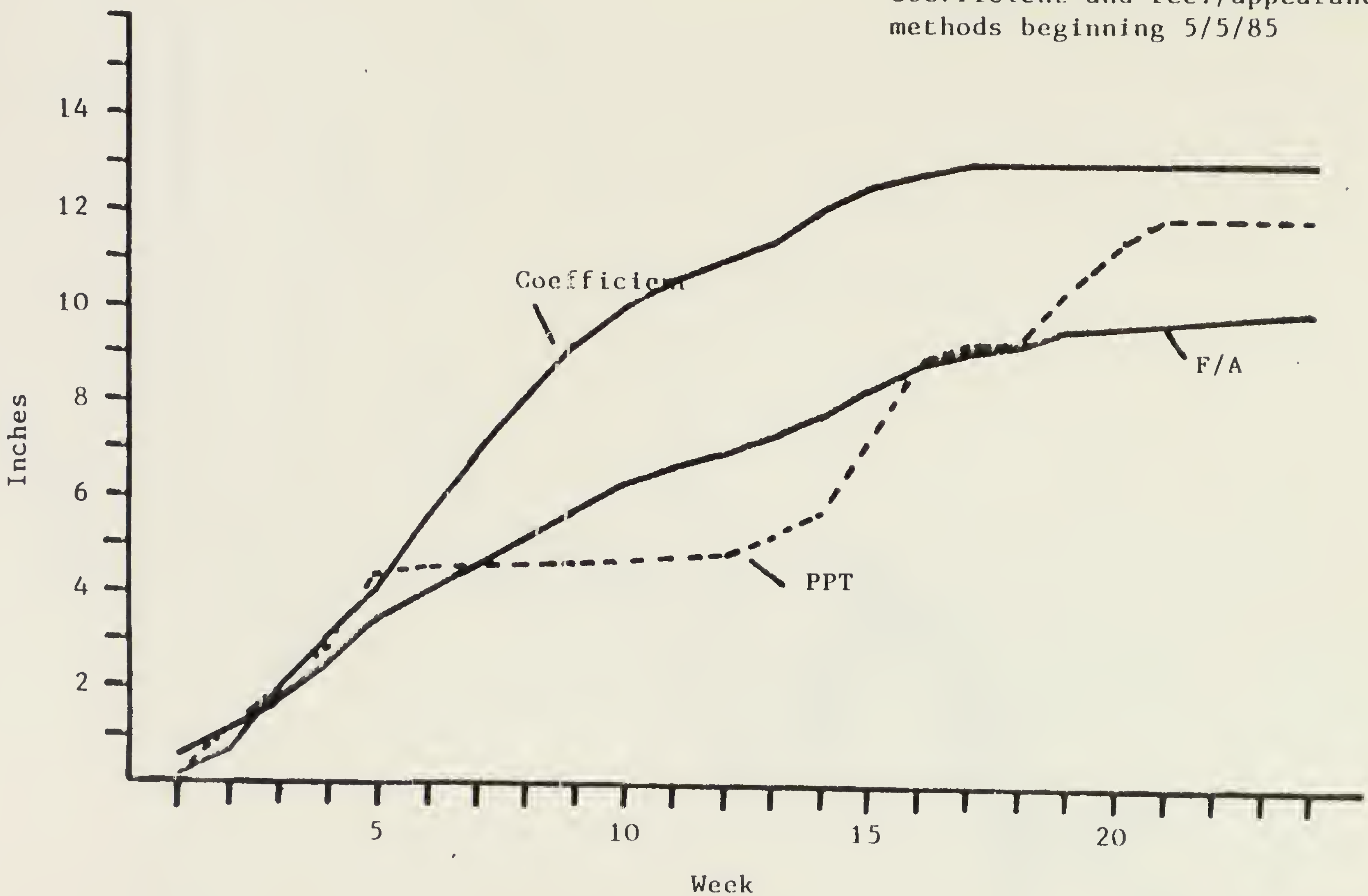


FIGURE 7. Barley - Johnson Site

Daily crop water use estimated by coefficient and feel/appearance method beginning 5/5/85.

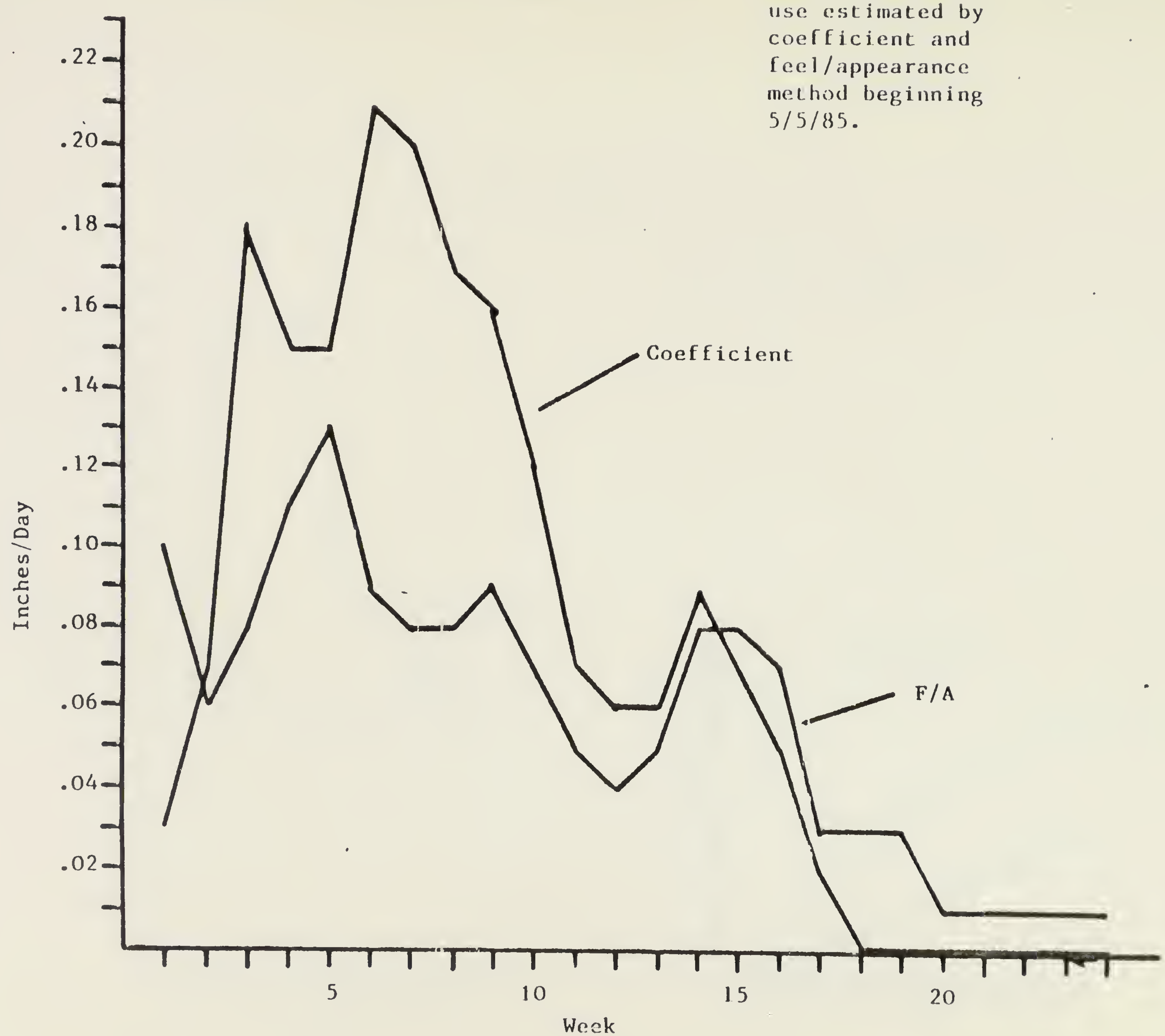
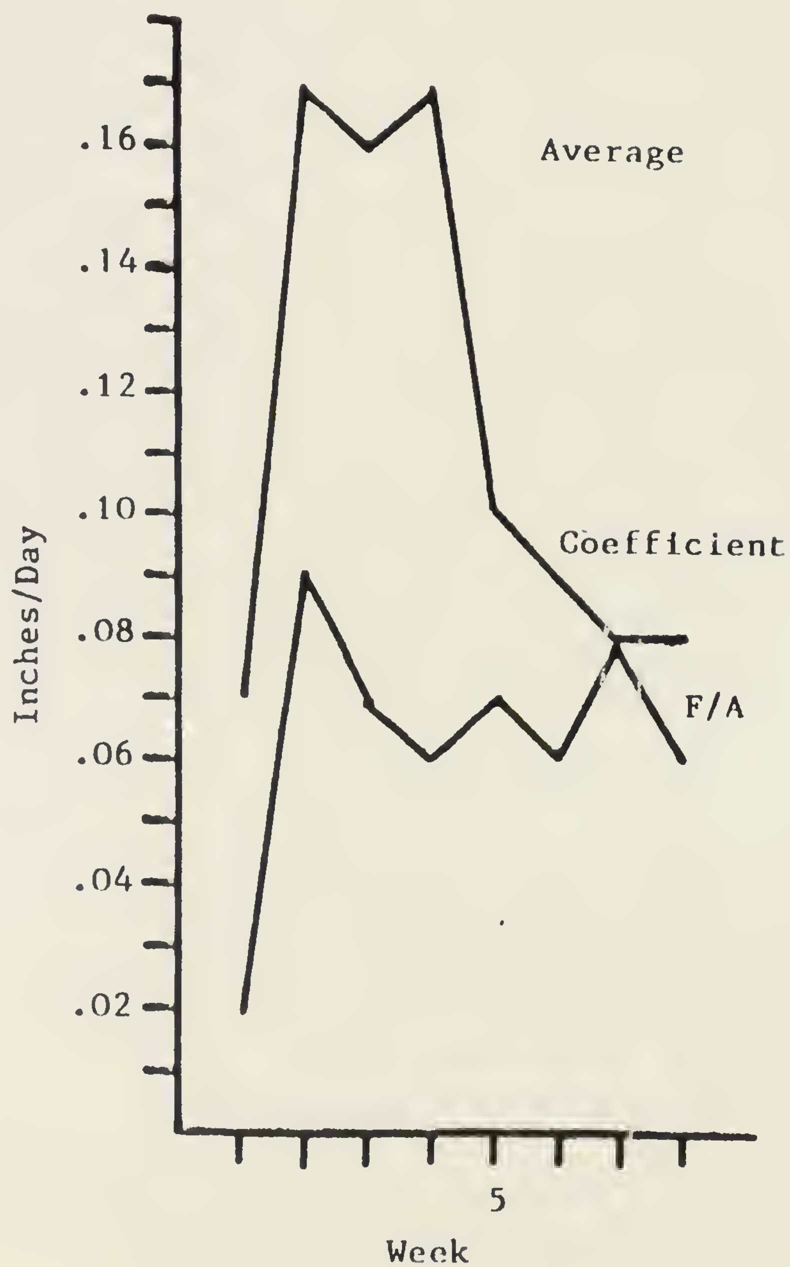


FIGURE 8. Winter Wheat – Chartier Site

Crop water use estimates by coefficient and feel/appearance methods



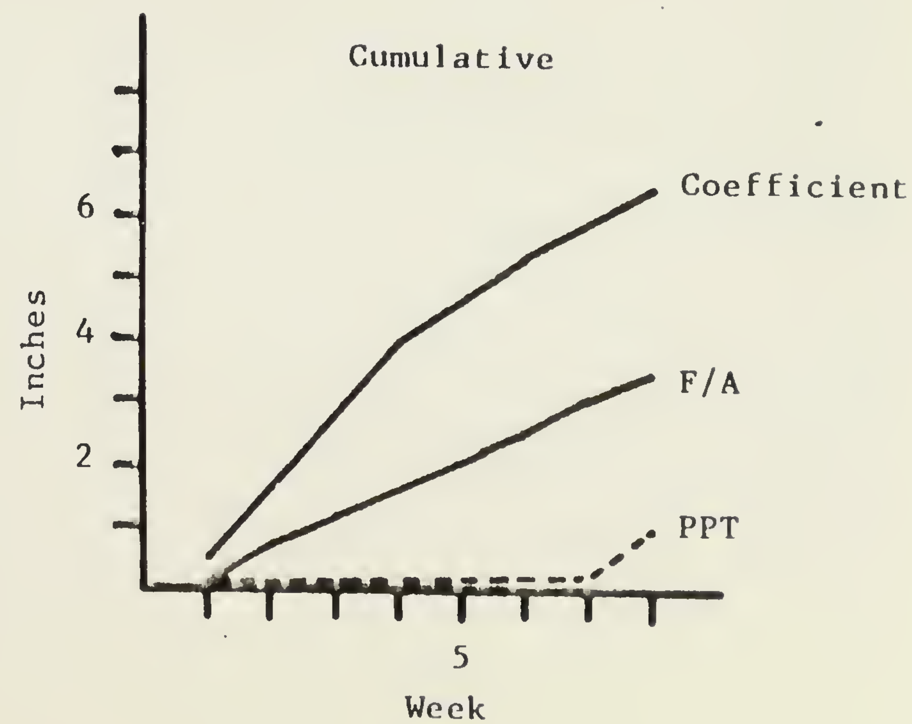


TABLE V.

Crop Water Use - Winter Wheat (Chartier)

Week	F/A Daily Average	F/A Cumulative	Co-efficient Daily Average	Co-efficient Cumulative
4/7 - 4/13	.02	.13	.07	.47
4/14 - 4/20	.09	.73	.17	1.67
4/21 - 4/27	.07	1.20	.16	2.78
4/28 - 5/4	.06	1.62	.17	3.98
5/5 - 5/11	.07	2.11	.10	4.70
5/12 - 5/18	.06	2.53	.09	5.35
5/19 - 5/25	.08	3.08	.08	5.91
5/26 - 6/1	.06	3.50	.08	6.47

Hailed Out

TABLE VI.

Summary of Water Budgets Based on F/A Method for All Sites

Grower	Crop	Cumulative ET for Season (in.)	Stored Soil Moisture At Planting	Stored Soil Moisture At Oct. 20	Total Season PPT	Deep Percolation*
Chartier	Alfalfa	11.64	4.20	3.08	10.60	0
	New Alfalfa	8.41	2.73	3.36	9.56	.52
	Winter Wheat +	(2.76)	3.57	1.05	.24	0
	Fallow	7.35	3.57	3.57	10.55	3.20
Johnson	Barley	9.95	3.46	5.41	12.10	.20
	Fallow	7.90	4.9	5.18	12.13	3.95

*Deep percolation = soil moisture at planting + ppt - ET - Oct. 20 soil moisture

+Winter Wheat - 4/7 to 6/1 only

TABLE VII.

CHARTIER SITE

DATE		RAINFALL (Inches)
4-20-85		.1
4-27-85		.05
	Total - April	.15
5-11-85		.07
5-21-85		.02
5-28-85		.80
	Total - May	.89
6-4-85		1.48
6-12-85		.10
	Total - June	1.58
7-3-85		.1
7-10-85		.25
7-24-85		.18
	Total - July	.53
8-2-85		.45
8-4-85		.80
8-13-85		.00
8-14-85		1.50
8-18-85		1.55
8-21-85		.25
8-28-85		.25
	Total - August	4.80
9-11-85		.85
9-15-85		1.00
9-25-85		.80
	Total - Sept.	2.65

Total April - October 10.60

JOHNSON SITE

DATE		RAINFALL (Inches)
4-20-85		.05
4-27-85		.00
	Total - April	.05
5-11-85		.11
5-21-85		.00
5-28-85		2.80
	Total - May	2.91
6-4-85		1.48
6-12-85		.10
	Total - June	1.58
7-3-85		.05
7-10-85		.00
7-24-85		.28
	Total - July	.33
8-2-85		.40
8-4-85		.55
8-13-85		.05
8-14-85		1.53
8-18-85		1.40
8-21-85		.25
8-28-85		.4
	Total - August	4.58
9-11-85		1.10
9-15-85		1.00
9-25-85		.60
	Total - Sept.	2.70

Total April - October 12.15

APPENDIX

CROP WATER USE BASED ON FEEL AND APPEARANCE

ıerator Chartier

rop Alfalfa-Grass

lanting Date 5/6/83

nergence Date 4/1/85

Rooting Depth: 8 - 10'

Profile Water Holding Capacity (PWHC) 4.20"

Year 1985

Page 1 of 3

›lumn:	A	B	C	D	E	F +	G *	H **	I	J
y/Date	% Field Capacity Begin	% Field Capacity End	Profile Water Content A x PWHC Begin	Profile Water Content B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
4/5										
4/10	100	90	4.20	3.78				.42	.08	.42
4/13	90	85	3.78	3.57				.21	.07	.63
4/16	85	80	3.57	3.36				.21	.07	.84
4/20	80	70	3.36	2.94	.1			.52	.13	1.36
4/24	70	65	2.94	2.73				.21	.05	1.57
4/27	65	60	2.73	2.52	.05			.26	.09	1.83
4/30	60	50	2.52	2.10			—	.42	.14	2.25
5/4	50	40	2.1	1.68				.42	.10	2.67
5/7	40	38	1.68	1.59				.09	.03	2.76
5/11	38	35	1.59	1.47	.07			.19	.05	2.95
5/14	35	30	1.47	1.26				.21	.07	3.16
5/18	30	25	1.26	1.05				.21	.05	3.37
5/21	25	20	1.05	.84	.02			.23	.08	3.60
5/28	20	55	.84	1.17	.80 [1.]		F.C. to 6"	.47	.08	4.07
6/4	55	85	1.17	2.30	1.48		F.C. to 13"	.35	.05	4.42
6/8	85	70	2.30	2.00				.30	.08	4.72
6/12	.70	50	2.00	1.54	.10			.56	.14	5.28
6/15	50	40	1.54	1.31				.23	.07	5.51
6/19	40	35	1.31	1.17				.14	.03	5.65
6/23	35	30	1.17	1.00				.17	.04	5.84

\+ F = (1 –A) x PWı

* G = E – F if E

** If both E & G =

H = C – D

If E 0 and G = 0

H = C + E – D

If both E & G 0

H = PWHC – D

1. at 20% FC, .80 in in water would only wet 6" to FC, if 55% of this is left 2.1 x .5 x .45 = .47" water use

CROP WATER USE BASED ON FEEL AND APPEARANCE

erator Chartler — Rooting Depth: 8-10' — Year 1985

op Alfalfa-Grass — Profile Water Holding Capacity (PWHC) 4.2 — Page 2 of 3

lanting Date 5/6/83

mergence Date 4/1/85

olumn:	A	B	C	D	E	F +	G *	H **	I	J
y/Date	% Field Capacity Begin	End	Profile Water Content A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
6/26	30	25	1.00	.83				.17	.06	6.01
6/30	25	20	.83	.66				.17	.04	6.18
7/3	20	15	.66	.50	.1			.26	.09	6.34
7/7	15	10	.50	.42				.08	.02	6.42
0 7/10	10	7	.42	.29	.25			.38	.13	6.80
6 7/16	7	3	.29	.17				.12	.02	6.94
1 7/21	3	0	.17	0				.17	.03	7.11
14 7/24	0	0	0	0	.18			.18	.06	7.27
8 7/28										7.27
1 7/31										7.27
3 8/2	0	85	0	.38	.45			.07	.04	7.34
5 8/6	85	*	.38	.77	.80			.41	.20	7.75
8 8/7	*	*	.77	.47	—			.30	.10	8.05
5 8/14	*	90	.47	1.76	1.50			.21	.03	8.26
9 8/18	90	85	1.76	2.81	1.55	F.C. to 12"		.50	.12	8.76
2 8/21	85	85	2.81	2.81	.25			.25	.08	9.01
6 8/25	85	75	2.81	2.48				.33	.08	9.34
9 8/28	75	80	2.48	2.64	.25			.09	.03	9.43
3 9/1	80	75	2.64	2.47				.17	.04	9.60
5 9/3	75	70	2.47	2.31				.16	.08	9.76
3 9/6	70	85	2.31	2.41	.85	FC to 16"		.75	.09	10.51

* No Soil Moisture Estimate Made

+ F = (1 - A) x PWH

* G = E - F if E

** If both E & G =

H = C - D

If E 0 and G = 0

H = C + E - D

If both E & G 0

H = PWHC - D

CROP WATER USE BASED ON FEEL AND APPEARANCE

ıerator Chartier
ːop Alfalfa-Grass
ˡanting Date 5/6/83
ıergence Date 4/1/85

Rooting Depth: 8-10'
Profile Water Holding Capacity (PWHC) 4.2

Year 1985
Page 3 of 3

ılumn:	A	B	C	D	E	F +	G *	H **	I	J
ıy/Date	% Field Capacity Begin	% Field Capacity End	Profile Water Content A x PWHC Begin	Profile Water Content B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
ı7 9/15	.85	.85	2.41	2.97	1.00	F.C. to 20"		.44	.11	. 10.95
77 9/25	.85	.85	2.97	3.27	.80	F.C. to 22"		.50	.05	11.45
)2 10/20	.85	.80	3.27	3.08	0			.19	.008	11.64
				Total	10.60					

+ F = (1-A) x R.
* G = E - F if E
** If both E & G
H = C - D
If E O and G = (
H = C + E - D
If both E & G O
H = PWHC - D

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator Chartier

Crop Alfalfa-Grass

Planting Date 5/6/83

Emergence Date 4/1/85

Cutting Date(s): Not cut due to drought

Rooting Depth: 8-10'

Profile Water Holding Capacity (PWHC) 4.20"

Year 1985

Page 1 of

Date	Days Post Emergence	Evaporation Pan Level Begin	Evaporation Pan Level End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
4/5/85	5	(8")									
4/10	10	8.00	7.38	.63		.63	.45	.85	.24	.05	.24
4/13	13	8.00	7.12	.88		.88	.50	.85	.37	.12	.61
4/16	16	8.00	7.12	.88		.88	.55	.80	.39	.13	1.00
4/20	20	8.25	7.00	1.25	.1	1.35	.60	.60	.48	.12	1.48
4/24	24	7.88	6.12	1.76		1.76	.65	.60	.68	.17	2.16
4/27	27	8.00	7.62	.38	.05	0.43	.70	.65	.19	.06	2.35
4/30	30	8.00	6.62	1.38		1.38	.75	.50	.52	.17	2.87
5/4	34	8.00	6.50	1.50		1.50	.80	.40	.48	.12	3.35
5/7	37	8.00	6.62	1.38		1.38	.85	.40	.47	.15	3.82
5/11	41	8.00	7.38	.62	.07	.69	.85	.35	.20	.05	4.02
5/14	44	8.00	6.75	1.25		1.25	.85	.30	.32	.11	4.34
5/18	48	8.00	6.75	1.25		1.25	.85	.25	.26	.07	4.60
5/21	51	8.00	6.75	1.25	.02	1.27	.85	.20	.22	.07	4.80
5/28	57	8.00	7.38	.62	.80	1.42	.85	.55	.66	.11	5.46
6/4	64	8.00	8.25	- .25	1.48	1.23	.85	.85	.89	.13	6.35
6/8	68	8.25	6.88	1.37		1.37	.85	.70	.81	.20	7.16
6/12	72	8.25	7.00	1.25	.10	1.35	.9	.50	.60	.15	7.76
6/16	75	8.00	6.25	1.75		1.75	.9	.40	.63	.21	8.39
6/19	79	8.00	6.88	1.12		1.12	.9	.35	.35	.09	8.74
6/23	83	8.00	5.88	2.12		2.12	.9	.30	.57	.14	9.31

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator Chartier

Crop Alfalfa-grass

Planting Date 5/6/83

Regrowth* Date 4/1/85

Cutting Date(s): Not cut due to drought

Rooting Depth: 8-10'

Profile Water Holding Capacity (PWHC) 4.20"

Year 1985

Date	Days Post Emergence	Evaporation Pan Level Begin	Evaporation Pan Level End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
6/26	86	8.00	7.12	.88		.88	.90	.25	.20	.07	9.51
6/30	90	8.00	6.00	2.00		2.00	.90	.2	.36	.09	9.87
7/3	93	8.00	6.88	1.12	.10	1.22	.90	.15	.16	.05	10.03
7/7	97	8.00	5.75	2.25		2.25	.90	.10	.20	.05	10.23
7/10	100	8.00	6.38	1.62	.25	1.87	.90	.10	.16	.05	10.39
7/16	106	8.00	5.00	3.00		3.00	.90	.10	.27	.04	10.66
7/21	111	8.00	5.62	2.38		2.38	.90	.10	.21	.04	10.87
7/24	114	8.00	6.88	1.12	.18	1.30	.90	.10	.12	.04	10.99
7/28	118	8.00	6.00	2.00		2.00	.90	.10	.18	.04	11.17
7/31	121	8.00	6.75	1.25		1.25	.90	.10	.11	.04	11.28
8/2	123	8.00	8.25	- .25	.45	.20	.85	.85	.14	.07	11.42
8/4	125	9.00	8.12	.88	.80	1.68	.85	.65	.92	.46	12.34
8/7	128	8.00	6.88	1.12		1.12	.85	.40	.38	.13	12.72
8/13							.80				
8/14	135	8.12	8.50	- .38	1.50	1.12	.80	(.90)+	.80	.11	13.52
8/18	139	8.00	9.25	- 1.25	1.55	.30	.80	(.85)+	.20	.05	13.72
8/21	142	8.50	8.00	.50	.25	.75	.80	(.85)+	.51	.17	14.23
8/25	146	9.25	6.88	2.37		2.37	.75	(.75)+	1.33	.33	15.56
8/28	149	8.00	7.50	.50	.25	.75	.75	.80	.45	.15	16.01
9/1	153	8.00	7.50	.50		.50	.75	.75	.28	.07	16.29
9/3	155	8.00	7.12	.88		.88	.75	.70	.46	.23	16.52

+Estimated

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator Chartier

Crop Alfalfa-Grass

Planting Date 5/6/83

Emergence Date 4/1/85

Cutting Date(s): Not cut due to drought

Rooting Depth: 8-10'

Profile Water Holding Capacity (PWHC) 4.2"

Year 1985

Date	Days Post Emergence	Evaporation Pan Level Begin	Evaporation Pan Level End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
9/11	163	8.00	8.38	- .38	.85	.47	.75	.85	.30	.04	16.82
9/15	167	8.00	8.38	- .38	1.00	.62	.75	.75	.34	.08	17.16
9/25	177	9.00	9.00	0	.80	.80	.75	.85	.51	.05	17.67
10/20	202	9.00	6.75	2.25	0	2.25	.75	.80	1.35	.05	19.02

CROP WATER USE BASED ON FEEL AND APPEARANCE

perator Chartier

rop New Alfalfa

lanting Date May 20, 1985

mergence Date June 3, 1985

Rooting Depth: 2-4'

Profile Water Holding Capacity (PWHC) 4.2'

Year 1985

Page 1 of 2

olumn:	A	B	C	D	E	F +	G *	H **	I	J
ay/Date	% Field Capacity Begin	End	Profile Water Content A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
1 6/4	65	90	2.73	3.78	1.48	1.47	.01	.42	.06	.42
2 6/8	90	80	3.78	3.36		---	—	.42	.10	.84
6/12	80	70	3.36	2.94	.10			.52	.13	1.36
13 6/16	70	60	2.94	2.52				.42	.10	1.78
16 6/19	60	55	2.52	2.31				.21	.07	1.99
0 6/23	55	50	2.31	2.10				.21	.05	2.20
3 6/26	50	45	2.10	1.89				.21	.07	2.41
7 6/30	45	40	1.89	1.68				.21	.05	2.62
30 7/3	40	35	1.68	1.47	.10			.31	.10	2.93
34 7/7	35	32	1.47	1.34				.13	.03	3.06
37 7/10	32	35	1.34	1.47	.25			.12	.04	3.18
43 7/16	35	30	1.47	1.26				.21	.04	3.39
48 7/21	30	25	1.26	1.05				.21	.04	3.60
1 7/24	25	25	1.05	1.05	.18			.18	.06	3.78
55 7/28	25	22	1.05	.92				.13	.03	3.91
58 7/31	22	19	.92	.80				.12	.04	4.03
60 8/2	19	85	.80	1.17	.45	F.C. to 3.2"		.08	.04	4.11
62 8/4	85	50	1.17	1.25	.80	F.C. to 8.3"		.72	.36	4.83
65 8/7	50	40	1.25	1.10				.15	.05	4.98
72 8/14	40	90	1.10	2.38	1.50	F.C. to 12.7"		.22	.03	5.20
76 8/18	90	85	2.38	3.45	1.55	F.C. to 18.2"		.48	.12	5.68

+ F = (1 - A) x PW

* G = E - F if E

** If both E & G

H = C - D

If E 0 and G = 0

H = C + E - D

If both E & G 0

H = PWHC - D

CRCP WATER USE BASED ON FEEL AND APPEARANCE

perator Chartier

rop New Alfalfa

lanting Date May 20, 1985

mergence Date June 3, 1985

Rooting Depth: 2-4'

Profile Water Holding Capacity (PWHC) 4.2'

Year 1985

Page 2 of 2

olumn:	A	B	C	D	E	F +	G *	H **	I	J
y/Date	% Field Capacity Begin	End	Profile Water Content A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
79 8/21	85	85	3.45	3.45	.25			.25	.08	5.93
3 8/25	85	80	3.45	3.25				.20	.05	6.13
86 8/28	80	80	3.25	3.25	.25			.25	.08	6.38
90 9/1	80	75	3.25	3.05				.20	.05	6.58
2 9/3	75	72	3.05	2.93				.12	.06	6.70
100 9/1	72	85	2.93	3.33	.85	F.C. to 17.3"		.45	.06	7.15
104 9/15	85	90	3.33	3.78	1.00	.87	.13	.42	.10	7.57
114 9/25	90	85	3.78	3.57	.80	.42	.38	.63	.06	8.20
139 10/20	85	80	3.57	3.36				.21	.01	8.41
				Total	9.56		.52			

+ F = (1 - A) x P

* G = E - F if E

** If both E & G

H = C - D

If E 0 and G = 0

H = C + E - D

If both E & G 0

H = PWHC - D

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator: Chartier
Crop: New Alfalfa
Planting Date: May 20, 1985
Emergence Date: June 3, 1985

Cutting Date(s): ---
Rooting Depth: 4'
Profile Water Holding Capacity (PWHC): 4.2

Year 1985

Date	Days Post Emergence	Evaporation Pan Level Begin	Evaporation Pan Level End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
6/4	1	8.00	8.25	- .25	1.48	1.23	.1	.90	.11	.02	.11
6/8	5	8.25	6.88	1.37	---	1.37	.30	.80	.33	.08	.44
6/12	9	8.25	7.00	1.25	.10	1.35	.50	.70	.47	.12	.91
6/16	13	8.00	6.25	1.75	---	1.75	.65	.60	.68	.17	1.59
6/19	16	8.00	6.88	1.12	---	1.12	.70	.55	.43	.14	2.02
6/23	20	8.00	5.88	2.12	---	2.12	.75	.50	.80	.20	2.82
6/26	23	8.00	7.12	.88	---	.88	.80	.45	.32	.11	3.14
6/30	27	8.00	6.00	2.00	---	2.00	.80	.40	.64	.16	3.78
7/3	30	8.00	6.88	1.12	.1	1.22	.80	.35	.34	.11	4.12
7/7	34	8.00	5.75	2.25	---	2.25	.80	.32	.57	.14	4.69
7/10	37	8.00	6.38	1.62	.25	1.87	.80	.35	.52	.17	5.21
7/16	43	8.00	5.00	3.00	---	3.00	.80	.30	.72	.12	5.93
7/21	48	8.00	5.62	2.38	---	2.38	.80	.25	.48	.09	6.41
7/24	51	8.00	6.88	1.12	.18	1.30	.80	.25	.26	.09	6.67
7/28	55	8.00	6.00	2.00	---	2.00	.80	.22	.35	.09	7.02
7/31	58	8.00	6.75	1.25	---	1.25	.80	.19	.19	.06	7.21
8/2	60	8.00	8.25	- .25	.45	.20	.80	.85	.14	.07	7.35
8/4	62	9.00	8.12	.88	.80	1.68	.80	.50	.67	.33	8.02
8/7	65	8.00	6.88	1.12	---	1.12	.80	.40	.36	.12	8.38
8/14	72	8.12	8.50	- .38	1.50	1.12	.80	.90	.80	.11	9.18
8/18	76	8.00	9.25	- 1.25	1.55	.2	.80	.85	.14	.03	9.32

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator: Chartier

Crop: New Alfalfa

Planting Date: May 20, 1985

Emergence Date: June 3, 1985

Cutting Date(s): ---

Rooting Depth: 4'

Profile Water Holding Capacity (PWHC): 4.2"

Year: 1985

Page 2 of 2

Date	Days Post Emergence	Evaporation Pan Level Begin	Evaporation Pan Level End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
8/21	79	8.50	8.00	.50	.25	.75	.80	.85	.51	.17	9.83
8/25	83	9.25	6.88	2.37	---	2.37	.80	.80	1.52	.38	10.35
8/28	86	8.00	7.50	.50	.25	.75	.80	.80	.48	.16	10.83
9/1	90	8.00	7.50	.50	---	.50	.80	.75	.30	.07	11.13
9/3	92	8.00	7.12	.88	---	.88	.80	.72	.51	.25	11.64
9/11	100	8.00	8.38	- .38	.85	.47	.80	.85	.32	.04	11.96
9/15	104	8.00	9.00	- 1.00	1.00	0	.80	.90	0	0	11.96
9/25	114	8.38	9.00	- .62	.80	.18	.80	.85	.12	.01	12.08
10/20	139	9.60	6.75	2.25	---	2.25	.80	.80	1.44	.06	13.52

CROP WATER USE BASED ON FEEL AND APPEARANCE

Operator Chartler

Crop Fallow

Planting Date

Emergence Date

Rooting Depth: ----

Profile Water Holding Capacity (PWHC) 4.2

Year 1985

Column:	A	B	C	D	E	F +	G *	H **	I	J
	% Field Capacity		Profile Water Content							
			A x PWHC	B x PWHC						
Date	Begin	End	Begin	End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
4/13		85		3.57						
4/16	85	80	3.57	3.36				.21	.07	.21
4/20	80	77	3.36	3.23	.1			.23	.06	.44
4/24	77	73	3.23	3.07				.16	.04	.60
4/27	73	70	3.07	2.94				.13	.04	.73
4/30	70	67	2.94	2.81				.13	.04	.86
5/4	67	63	2.81	2.65				.16	.04	1.02
5/7	63	60	2.65	2.52				.13	.04	1.15
5/11	60	57	2.52	2.39	.07			.20	.05	1.35
5/14	57	53	2.39	2.23				.16	.05	1.51
5/21	53	50	2.23	2.10	.02			.15	.02	1.66
5/28	50	60	2.10	2.52	.80			.37	.05	2.03
6/4	60	90	2.52	3.78	1.48	1.58	—	.22	.03	2.25
6/8	90	85	3.78	3.57				.21	.07	2.46
6/12	85	83	3.57	3.49	.10			.18	.04	2.64
6/16	83	77	3.49	3.23		Plowed		.26	.06	2.90
6/19	77	73	3.23	3.07				.16	.05	3.06
6/23	73	67	3.07	2.81		Plowed		.26	.06	3.32
6/26	67	63	2.81	2.65				.16	.05	3.48
6/30	63	60	2.65	2.52				.13	.03	3.61
7/3	60	57	2.52	2.40	.1			.22	.07	3.83

+ F = (1 - A) x I

* G = E - F if

** If both E & G

H = C - D

If E 0 and G =

H = C + E - D

If both E & G 0

H = PWHC - D

CROP WATER USE BASED ON FEEL AND APPEARANCE

Operator Chartier

Crop Fallow

Planting Date

Emergence Date

Rooting Depth: ----

Profile Water Holding Capacity (PWHC) 4.2

Year 1985

Page 2 of 2

Column:	A	B	C	D	E	F +	G *	H **	I	J
	% Field Capacity		Profile Water Content							
Date	Begin	End	A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
7/7	57	55	2.40	2.31				.09	.02	3.92
7/10	55	57	2.31	2.40	.25			.16	.05	4.08
7/16	57	53	2.40	2.23				.17	.03	4.25
7/21	53	50	2.23	2.10				.13	.03	4.38
7/24	50	50	2.10	2.10	.18			.18	.06	4.56
7/28	50	47	2.10	1.97				.13	.03	4.69
7/31	47	45	1.97	1.89				.08	.03	4.77
8/2	45	85	1.89	2.22	.45	FC to 4.7		.12	.06	4.89
8/4	85	90	2.22	2.78	.80	FC to 13.7		.24	.12	5.13
8/7	90	85	2.78	2.66				.12	.04	5.25
8/14	85	92	2.66	3.83	1.50	1.54 FC to 23.6"		.33	.05	5.58
8/18	92	95	3.83	3.99	1.55	.37	1.18	.21	.05	5.79
8/21	95	95	3.99	3.99	.25	.21	.04	.21	.07	6.00
8/25	95	92	3.99	3.86	—			.13	.03	6.13
8/28	92	95	3.86	3.99	.25	.34		.12	.04	6.25
9/1	95	92	3.99	3.86				.13	.03	6.38
9/3	92	90	3.86	3.78				.08	.04	6.46
9/11	90	97	3.78	4.07	.85	.42	.43	.13	.02	6.59
9/15	97	97	4.07	4.07	1.00	.13	.87	.13	.03	6.72
9/25	97	95	4.07	3.99	.80	.13	.67	.21	.02	6.93
10/20	95	85	3.99	3.57				.42	.02	7.35
Total					10.55		3.19			

+ F = (1 -A) x P

* G = E - F if

** If both E & G

H = C - D

If E 0 and G =

H = C + E - D

If both E & G 0

H = PWHC - D

CROP WATER USE BASED ON FEEL AND APPEARANCE

Operator Johnson

Crop Fallow

Planting Date

Emergence Date

Rooting Depth: ----

Profile Water Holding Capacity (PWHC) 5.76

Year 1985

Page 1 of 3

Column:	A	B	C	D	E	F +	G *	H **	I	J
	% Field Capacity		Profile Water Content							
Date	Begin	End	A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
4/13		85		4.90						
4/16	85	83	4.90	4.78				.12	.04	.12
4/20	83	80	4.78	4.61	.05			.22	.05	.34
4/24	80	77	4.61	4.44				.17	.04	.51
4/27	77	75	4.44	4.32				.12	.04	.63
4/30	75	73	4.32	4.20				.12	.04	.75
5/4	73	70	4.20	4.03				.17	.04	.92
5/7	70	68	4.03	3.92				.11	.04	1.03
5/11	68	65	3.92	3.74	.11			.29	.07	1.32
5/14	65	63	3.74	3.63				.11	.04	1.43
5/18	63	60	3.63	3.46		Plowed		.17	.04	1.60
5/21	60	57	3.46	3.28				.18	.06	1.78
5/28	57	90	3.28	5.18	2.80	2.48	.32	.58	.08	2.36
6/4	90	90	5.18	5.18	1.48	.58	.90	.58	.08	2.94
6/8	90	87	5.18	5.01				.17	.04	3.11
6/12	87	85	5.01	4.90	.10			.21	.05	3.32
6/16	85	82	4.90	4.72				.18	.04	3.50
6/19	82	80	4.72	4.61				.11	.04	3.61
6/23	80	77	4.61	4.44				.17	.04	3.78
6/26	77	75	4.44	4.32				.12	.04	3.90
6/30	75	72	4.32	4.15				.17	.04	4.07

+ F = (1 - A) x P

* G = E - F if

** If both E & G

H = C - D

If E 0 and G =

H = C + E - D

If both E & G 0

H = PWHC - D

CROP WATER USE BASED ON FEEL AND APPEARANCE

Operator: Johnson
Crop: Fallow
Planting Date: ______
Emergence Date: ______

Rooting Depth: ----
Profile Water Holding Capacity (PWHC): 5.76

Year: 1985

Column:	A	B	C	D	E	F +	G *	H **	I	J
	% Field Capacity		Profile Water Content							
Date	Begin	End	A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
7/3	72	70	4.15	4.03	.03			.15	.05	4.22
7/7	70	67	4.03	3.86	——			.17	.04	4.39
7/10	67	65	3.86	3.74	——			.12	.04	4.51
7/16	65	62	3.74	3.57	——			.17	.03	4.68
7/21	62	60	3.57	3.46	——			.11	.02	4.74
7/24	60	62	3.46	3.57	.28			.17	.06	4.96
7/28	62	60	3.57	3.46	——			.11	.04	5.07
7/31	60	58	3.46	3.34	——			.12	.04	5.19
8/2	58	85	3.34	3.60	.40	FC to 8.0"		.14	.07	5.33
8/4	85	90	3.60	3.99	.55	FC to 14.0"		.16	.08	5.49
8/7	90	80	3.99	3.82	——			.17	.06	5.66
8/13	80	75	3.82	3.74	.05			.13	.02	5.79
8/14	75	98	3.74	5.20	1.53	FC to 30" 2.02		.07	.07	5.86
8/18	98	95	5.20	5.47	1.40	.56	.84	.29	.07	6.15
8/21	95	95	5.47	5.47	.25	.29		.25	.08	6.40
8/25	95	93	5.47	5.36	——			.11	.02	6.51
8/28	93	97	5.36	5.59	.40	.40		.17	.06	6.68
9/1	97	95	5.59	5.47				.12	.03	6.80
9/3	95	94	5.47	5.41	——			.06	.03	6.86
9/11	94	95	5.41	5.47	1.10	.35	.75	.29	.04	7.15
9/15	95	97	5.47	5.59	1.00	.29	.71	.17	.04	7.32

+ F = (1-A) x P...
* G = E - F if E...
** If both E & G...
H = C - D
If E O and G = O
H = C + E - D
If both E & G O
H = PWHC - D

CROP WATER USE BASED ON FEEL AND APPEARANCE

Operator Johnson

Crop Fallow

Planting Date

Emergence Date

Rooting Depth: ----

Profile Water Holding Capacity (PWHC) 5.76

Year 1985

Column:	A	B	C	D	E	F +	G *	H **	I	J
Date	% Field Capacity Begin	% Field Capacity End	Profile Water Content A x PWHC Begin	Profile Water Content B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
9/25	97	95	5.59	5.47	.60	.17	.43	.29	.03	7.61
10/20	95	90	5.47	5.18	—			.29	.01	7.90
			TOTAL		12.13		3.95			

+ F = (1-A) x PW...

* G = E - F if E

** If both E & G ...

H = C - D

If E 0 and G = 0

H = C + E - D

If both E & G 0

H = PWHC - D

CROP WATER USE BASED ON FEEL AND APPEARANCE

perator Johnson

rop Barley

lanting Date

mergence Date May 1, 1985

Rooting Depth: 4'

Profile Water Holding Capacity (PWHC) 5.76

Year 1985

Page 1 of 2

olumn:	A	B	C	D	E	F +	G *	H **	I	J
	% Field Capacity		Profile Water Content							
ate	Begin	End	A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
5/4		60		3.46	--					
5/7	60	55	3.46	3.18	--			.28	.09	.28
5/11	55	50	3.18	2.88	.11			.41	.10	.69
5/14	50	47	2.88	2.71	--			.17	.06	.86
5/18	47	43	2.71	2.48	--			.23	.06	1.09
5/21	43	40	2.48	2.31	--			.17	.06	1.26
5/28	40	85	2.31	4.41	2.80	F.C. to 39"		.70	.10	1.96
6/4	85	85	4.41	4.90	1.48	1.35	.13	.86	.12	2.82
6/8	85	75	4.90	4.32	--			.58	.14	3.40
6/12	75	70	4.32	4.03	.10			.39	.10	3.79
6/16	70	65	4.03	3.74	--			.29	.07	4.08
6/19	65	60	3.74	3.46	--			.28	.09	4.36
6/23	60	55	3.46	3.17	--			.29	.07	4.65
6/26	55	50	3.17	2.88	--			.29	.10	4.94
6/30	50	45	2.88	2.59	--			.29	.07	5.23
7/3	45	40	2.59	2.30	.05			.34	.11	5.57
7/7	40	35	2.30	2.02	--			.28	.07	5.85
7/10	35	30	2.02	1.73	--			.29	.10	6.14
7/16	30	25	1.73	1.44	--			.29	.05	6.43
7/21	25	20	1.44	1.15	--			.29	.06	6.72
7/24	20	22	1.15	1.28	.28			.15	.05	6.87

+ F = (1 – A) x PWH

* G = E – F if E

** If both E & G =

H = C – D

If E 0 and G = 0

H = C + E – D

If both E & G 0

H = PWHC – D

CROP WATER USE BASED ON FEEL AND APPEARANCE

erator Johnson | Rooting Depth: 4' | Year 1985

rop Barley | Profile Water Holding Capacity (PWHC) 5.77 | Page 2 of 2

lanting Date

mergence Date May 1, 1985

lumn:	A	B	C	D	E	F +	G *	H **	I	J
	% Field Capacity		Profile Water Content							
te	Begin	End	A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
/28	22	20	1.28	1.15	--			.13	.03	7.00
/31	20	18	1.15	1.04	—			.11	.04	7.11
/2	18	85	1.04	1.37	.40	F.C. to 4"		.07	.04	7.18
/4	85	80	1.37	1.66	.55	F.C. to 10.8"		.26	.13	7.44
/7	80	60	1.66	1.40	—			.26	.09	7.70
/13	60	40	1.40	1.14	.05			.31	.05	8.01
/14	40	95	1.14	2.56	1.53	F.C. to 18.4"		.11	.11	8.12
/18	95	90	2.56	3.58	1.40	F.C. to 31.5"		.38	.10	8.50
/21	90	90	3.58	3.58	.25			.25	.08	8.75
/25	90	85	3.58	3.38	—			.20	.05	8.95
8/28	85	100	3.38	3.68	.40	OFF		.10	.03	9.05
9/1	100	95	3.68	3.58	—			.10	.03	9.15
9/3	95	92	3.58	3.48	—			.06	.03	9.21
9/11	92	75	3.48	4.31	1.10			.27	.03	9.48
9/15	75	90	4.31	5.19	1.00			.12	.03	9.60
9/25	90	98	5.19	5.66	.60	.57	.03	.10	.01	9.70
10/20	98	94	5.66	5.41	—			.25	.01	9.95
				Total	12.10		.16			

+ F = (1 - A) x PWHC

* G = E - F if E

** If both E & G =

H = C - D

If E 0 and G = 0

H = C + E - D

If both E & G 0

H = PWHC - D

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator Johnson

Crop Barley

Planting Date

Emergence Date May 1, 1985

Cutting Date(s): August 28, 1985

Rooting Depth: 4'

Profile Water Holding Capacity (PWHC) 5.77

Date	Days Post Emergence	Evaporation Pan Level Begin	Evaporation Pan Level End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
5/7	7	8.00	6.38	1.62	—	1.62	.10	.55	.09	.01	.09
5/11	11	8.00	7.25	.75	.11	.86	.25	.50	.11	.03	.20
5/14	14	8.00	6.25	1.75		1.75	.40	.47	.33	.11	.53
5/18	18	8.00	7.25	.75		.75	.50	.43	.16	.04	.69
5/21	21	8.00	6.00	2.00		2.00	.60	.40	.48	.16	1.17
5/28	28	8.00	8.25	- .25	2.80	2.55	.65	.85	1.40	.20	2.57
6/4	35	8.00	8.25	- .25	1.48	1.23	.80	.85	.83	.12	3.40
6/8	39	8.00	6.88	1.12	—	1.12	.80	.75	.67	.17	4.07
6/12	43	8.50	7.12	1.38	.10	1.48	.80	.70	.82	.20	4.89
6/16	47	8.00	6.25	1.75	—	1.75	.80	.65	.91	.23	5.80
6/19	50	8.00	6.88	1.12	—	1.12	.80	.60	.53	.18	6.33
6/23	54	8.00	6.00	2.00	—	2.00	.80	.55	.88	.22	7.21
6/26	57	8.00	7.00	1.00	—	1.00	.80	.50	.40	.13	7.61
6/30	61	8.00	6.00	2.00	—	2.00	.80	.45	.72	.18	8.33
7/3	64	8.00	7.00	1.00	.05	1.05	.80	.40	.33	.11	8.66
7/7	68	8.00	5.25	2.75	—	2.75	.80	.35	.77	.19	9.43
7/10	71	8.00	6.25	1.75	—	1.75	.80	.30	.42	.14	9.85
7/16	77	8.00	5.75	2.25	—	2.25	.80	.25	.45	.07	10.30
7/21	82	8.00	5.50	2.50	—	2.50	.75	.20	.37	.07	10.67
7/24	85	8.00	6.88	1.12	.28	1.40	.60	.22	.18	.06	10.85
7/28	89	8.00	6.00	2.00	—	2.00	.55	.20	.22	.05	11.07

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator Johnson
Crop Barley
Planting Date
Emergence Date May 1, 1985

Cutting Date(s): August 28, 1985
Rooting Depth: 4'
Profile Water Holding Capacity (PWHC) 5.77

Year 1985
Page 2 of 2

Date	Days Post Emergence	Evaporation Pan Level Begin	Evaporation Pan Level End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
7/31	92	8.00	6.75	1.25	—	1.25	.50	.18	.11	.04	11.18
8/2	94	8.00	8.38	- .38	.40	.02	.45	.85	.02	.01	11.20
8/4	96	8.88	7.88	1.00	.55	1.55	.40	.80	.50	.25	11.70
8/7	99	8.00	6.62	1.38	—	1.38	.40	.60	.33	.11	12.03
8/13	105	9.00	8.50	.50	.05	.55	.35	.40	.08	.01	12.11
8/14	106	8.62	8.50	- .12	1.53	1.41	.35	.95	.46	.46	12.57
8/18	110	8.00	9.25	- 1.25	1.40	.15	.30	.90	.04	.01	12.61
8/21	113	8.50	8.50	0	.25	.25	.30	.90	.07	.02	12.68
8/25	117	9.25	7.50	1.75	—	1.75	.20	.85	.30	.07	12.98
8/28	120	8.50	7.38	1.12	.40	1.52	.05	1.00	.08	.03	13.06
9/1	124	8.00	7.25	.75	—	.75	.01	.95	.01	—	13.07
9/3	126	8.00	7.12	.88	—	.88	0	.92	0	0	
9/11	134	8.00	8.88	- .88	1.10	.22	0	.75	0	0	
9/15	138	8.00	8.88	- .88	1.00	.12	0	.90	0	0	
9/25	148	8.88	8.38	.50	.60	1.10	0	.98	0	0	
10/20	173	8.88	7.00	1.88	—	1.88	0	.94	0	0	

CROP WATER USE BASED ON FEEL AND APPEARANCE

Operator Chartler | Rooting Depth: 4' | Year 1985

Crop Winter Wheat | Profile Water Holding Capacity (PWHC) 4.2 | Page 1 of 1

Planting Date Fall '84

Emergence Date

Column:	A	B	C	D	E	F +	G *	H **	I	J
	% Field Capacity		Profile Water Content							
Day/Date	Begin	End	A x PWHC Begin	B x PWHC End	Total Rainfall	Beginning Water Deficit	Deep Percolation	Water Use	Avg. Daily	Cumulative Water Use
10 4/10	.85		3.57							
13 4/13	.85	.82	3.57	3.44		—	—	.13	.04	.13
16 4/16	.82	.80	3.44	3.36				.08	.03	.21
20 4/20	.80	.70	3.36	2.94	.1			.52	.13	.73
24 4/24	.70	.65	2.94	2.73				.21	.05	.94
27 4/27	.65	.60	2.73	2.52	.05			.26	.09	1.20
30 4/30	.60	.55	2.52	2.31				.21	.07	1.41
34 5/4	.55	.50	2.31	2.10				.21	.05	1.62
41 5/11	.50	.40	2.10	1.68	.07			.49	.07	2.11
44 5/14	.40	.35	1.68	1.47				.21	.07	2.32
48 5/18	.35	.30	1.47	1.26				.21	.05	2.53
51 5/21	.30	.25	1.26	1.05	.02			.23	.08	2.76

Received .80" 5/28; Hailed out 6/1

+ F = (1 -A) x P

* G = E - F if

** If both E & G

H = C - D

If E 0 and G =

H = C + E - D

If both E & G 0

H = PWHC - D

COEFFICIENT METHOD OF ESTIMATING CROP WATER USE

Operator Chartier

Crop Winter Wheat

Planting Date Fall '84

Emergence Date

Cutting Date(s):

Rooting Depth: 4'

Profile Water Holding Capacity (PWHC) 4.2"

Year 1985

Page 1 of 1

Date	Days Post Emergence	Evaporation Pan Level Begin	End	Change in Pan Level	Rainfall	PET	Crop Coefficient	Soil Moisture Coefficient	ET	Avg. Daily ET	Cumulative ET
4/13	13	8.00	7.12	.88	—	.88	.65	.82	.47	.06	.47
4/16	16	8.00	7.12	.88	—	.88	.70	.80	.49	.16	.96
4/20	20	8.25	7.00	1.25	.1	1.35	.75	.70	.71	.18	1.67
4/24	24	7.88	6.12	1.76	—	1.76	.80	.65	.91	.23	2.58
4/27	27	8.00	7.62	.38	.05	.43	.80	.60	.20	.07	2.78
4/30	30	8.00	6.62	1.38	—	1.38	.80	.55	.60	.20	3.38
5/4	34	8.00	6.50	1.50	—	1.50	.80	.50	.60	.15	3.98
5/7	37	8.00	6.62	1.38	—	1.38	.80	.45	.50	.17	4.48
5/11	41	8.00	7.38	.62	.07	.69	.80	.40	.22	.06	4.70
5/14	44	8.00	6.75	1.25	—	1.25	.80	.35	.35	.12	5.05
5/18	48	8.00	6.75	1.25	—	1.25	.80	.30	.30	.08	5.35
5/21	51	8.00	6.75	1.25	—	1.25	.80	.25	.25	.08	5.60

APPENDIX II - EXPLANATION FOR SE GREAT FALLS AND STOCKETT QUADRANGLES, MONTANA

--------------------------------HOLOCENE--------------------------------

Hal ALLUVIUM--unconsolidated, stratified alluvial deposits of light brown, fine-grained sand, silt and clay with lenses and beds of coarser detritus; deposits of fluvial origin.

Hcl COLLUVIUM--unstratified, unconsolidated colluvial deposits of light and medium brown sand, silt and clay, contain variable amount of large angular boulders and cobbles of sandstone; deposits formed by mass wasting processes in part modified by fluvial processes.

He EOLIAN DEPOSITS--unconsolidated, windblown fine sand, in places forming semiactive eolian dunes 3-5 feet (1-2 m).

--------------------------------PLEISTOCENE--------------------------------

P_Lt TILL--unconsolidated, nonstratified, nonsorted deposits of rounded boulders and cobbles in unsorted matrix of coarse sand and gravel; Wisconsin age.

P_Ll_1 LACUSTRINE BEDS--unconsolidated, stratified lacustrine deposits, associated with the Wisconsin-age glacial lake Great Falls, of medium-brown, poorly-sorted sand, silt and clay with lenses and beds of coarser detritus in the Gibson and Johnson Flats areas which are believed to be abandoned channel of Missouri River; grades into fluvial deposits along Tributary streams (Coulee Creek and Walker, Spring, and Ming coulees).

P_Ltd TERRACE DEPOSITS--unconsolidated, stratified deposits of older alluvium found on distinct terrace surfaces adjacent to the abandoned channel of the Missouri River.

P_Lg_1 LOWER GRAVEL DEPOSITS--unconsolidated, stratified deposits of older alluvium composed of poorly sorted, well rounded pebble/cobble conglomerate with an unsorted matrix of sand, silt and clay

P_Ll_2 OLDER LACUSTRINE BEDS--stratified, unconsolidated lacustrine deposits of well laminated dark gray mudstone with lenses of claystone interbedded with medium-gray, layered to more massive bedded mudstone; locally contains scattered pebbles; underlies P_Lg_1 in gravel pit east of Gibson Flats.

P_Lg_2 HIGHER GRAVEL DEPOSITS--unconsolidated, stratified deposits of older alluvial gravels composed of poorly sorted, well rounded pebble/cobble sandy conglomerate.

--------------------------------CRETACEOUS--------------------------------

Kbf BLACKLEAF FORMATION--Only the basal sandstone is exposed which is medium-grained thin- to medium-bedded mature quartz arenite with abundant ripple marks and invertebrate trace fossils. 30 m exposed in map area.

Kk_5
Kk_4
Kk_3
Kk_{2A}/Kk_{2B}
Kk_1

KOOTENAI FORMATION--Dominantly gray chert-rich sandstone and red mudstone containing lensesand beds of limestone, mapped as five members.

Fifth member (Kk_5)--Dominantly red mudstone containing lenses of sandstone and limestone. A persistent of ostracod-rich limestone beds up to 6 m thick, occurs at the base and is overlain by dark fissile shale and fine-grained sandstone. This is overlain by a lignite zone 12 to 15 m thick composed of claystone And siltstone with stringers of lignite. Lenticular beds of sandstone overlie the lignite zone. Sandstones are composed of quartz, hornblende, biotite, dark chert, orange feldspar and are planar-bedded with beds 2 to 5 cm thick. Large iron concretions up to one m in diameter are also common. The uppermost part of

the member consists of 45 to 60 m of massive, color-banded, greenish-gray, purple, reddish-orange and maroon mudstone with lenses of fine- to medium-grained trough-crossbedded, greenish-gray-weathering sandstone composed of quartz, dark chert, muscovite, biotite and sand-size ironstone grains. Ironstone concretions are also abundant in the mudstone. Member thickness ranges from 30 to 50 m.

Fourth member (Kk_4)--Red to maroon fine- to medium-grained, thin- to medium-bedded micaceous, argillaceous, platy-bedded litharenite, rhythmically interbedded with red mudstone. Basal contact is transitional with Kk_3 and contains interbedded gray or red siltstone and mudstone. Lowest sandstone beds are orangish-gray- or brownish-gray-weathering, becoming red or maroon higher in the section. Low amplitude ripple marks, which are locally interference ripples commonly occur on bedding surfaces. Member thickness ranges from 20 to 30 m.

Third member (Kk_3)--Well sorted resistant quartz arenite generally with about 89% quartz and interspersed limonite specks and 2% white matrix clay. Scour base with rip-up clasts and occasional chert pebbles cuts into Second member. In the Centerville area Third member rests disconformable on First member. Up to 20% dark chert is present at base, but higher in section it disappears entirely in most areas. Primary sedimentary structures include planar, tabular crossbedding with sets generally 20 to 40 cm thick and planar-bedded fine-grained sandstone and siltstone in 2 to 10 cm thick beds separating sets. Sinous and straight-crested wave and interference ripple marks occur on bedding surfaces. Interbedded sandstone, siltstone and shale occur in planar beds near the top of the member with abundant invertebrate fossils on bedding surfaces and within beds. Member thickness ranges from 6 to 30 m.

Second member, facies B (Kk_{2B})--Poorly resistant red mudstone which overlies the First member with a sharp contact and represents a facies equivalent of Second member, Facies A. Mudstone contains dense gray micrite and argillaceous, tan-gray micrite concretions which laterally becomes lenticular, irregular beds. Thin, lenticular chert-rich quartz arenite beds occur locally. They are fine-grained sandstone to chert granule conglomerate which contain granule- to pebble-size intraformational micrite clasts. Member thickness ranges from 0 to 30 m.

Second member, facies A (Kk_{2A})--Variable unit which overlies First member with a gradational contact and represents a facies equivalent of Second member, facies B. In Sand and Mining Coulees, consists dominantly of quartz arenite similar in lithology and sedimentary structures to First member, except less cemented, and interbedded with light gray or yellow-brown calcareous mudstone. In the Sand Coulee- Centerville-Number Seven area, and in Mining Coulee, member contains a bed of fine-grained planar-bedded light gray sandstone with red or purple mottling of Leisegang banding near the base, and light gray sandstone beds with medium to coarse angular black and reddish-orange chert and light gray quartz grains supported in a matrix of fine-grained sand or clay. Locally contains intraformational rip-up clasts up to cobble size. These beds, which range from 30 cm to 7.5 m thick, are interbedded with light gray shale which also contains matrix-supported angular chert and quartz grains. At Goon and Walker coulees, unit contains interbedded lithologies of First member; Second member facies B; Third member; and greenish-gray shale. In most areas, member contains a light-gray fine-grained ortho-quartzite bed from 30 to 50 cm thick with angular matrix-supported medium- or coarse-grained chert and sandstone grains. Member thickness ranges from 0 to 30 m.

First member (Kk_1)--Dominantly resistant festoon-crossbedded, moderately well sorted quartz arenite with 20-50% black, dark and light gray chert. Coarse-grained sandstone, chert granule conglomerate or chert pebble conglomerate occurs at scour base, typically with abundant rip-up clasts of coal, plant fragments and impressions, and occasional cobble-size chert clasts. Boulder and cobble conglomerate occurs in local zones at the base with rounded cobbles of chert and subrounded to subangular boulder of sandstone. Grain size fines upward with upper part of member generally fine- to medium grained. Member thickness ranges from 10 cm to 30 m.

-----------------------------JURASSIC-----------------------------------

Jm MORRISON FORMATION --Light greenish-gray mudstone and shale with interbedded lenses and beds of gray micrite and fine- to medium-grained calcareous thin-bedded yellowish-brown-weathering limonitic sandstone. Base is transitional with underlying Swift Formation. Black shale and bituminous coal occur at top of formation, overlying transitional gray shale. Formation thickness ranges from 26 to 60 m.

Js SWIFT FORMATION--Orangish-brown-weathering, gray or tan calcareous, glauconitic fine- to coarse-grained sandstone containing local fossil hash of pelecypod shells and interbeds of gray shale. Conglomeratic scour base rests unconformably on Mission Canyon Formation and contains rounded black chert pebbles and subrounded to subangular clasts of Mission Canyon Limestone up to large cobble size. Underlying Rierdon and Sawtooth Formations of Ellis Group are missing in this area.

Formation thickness ranges from one to 12 m.

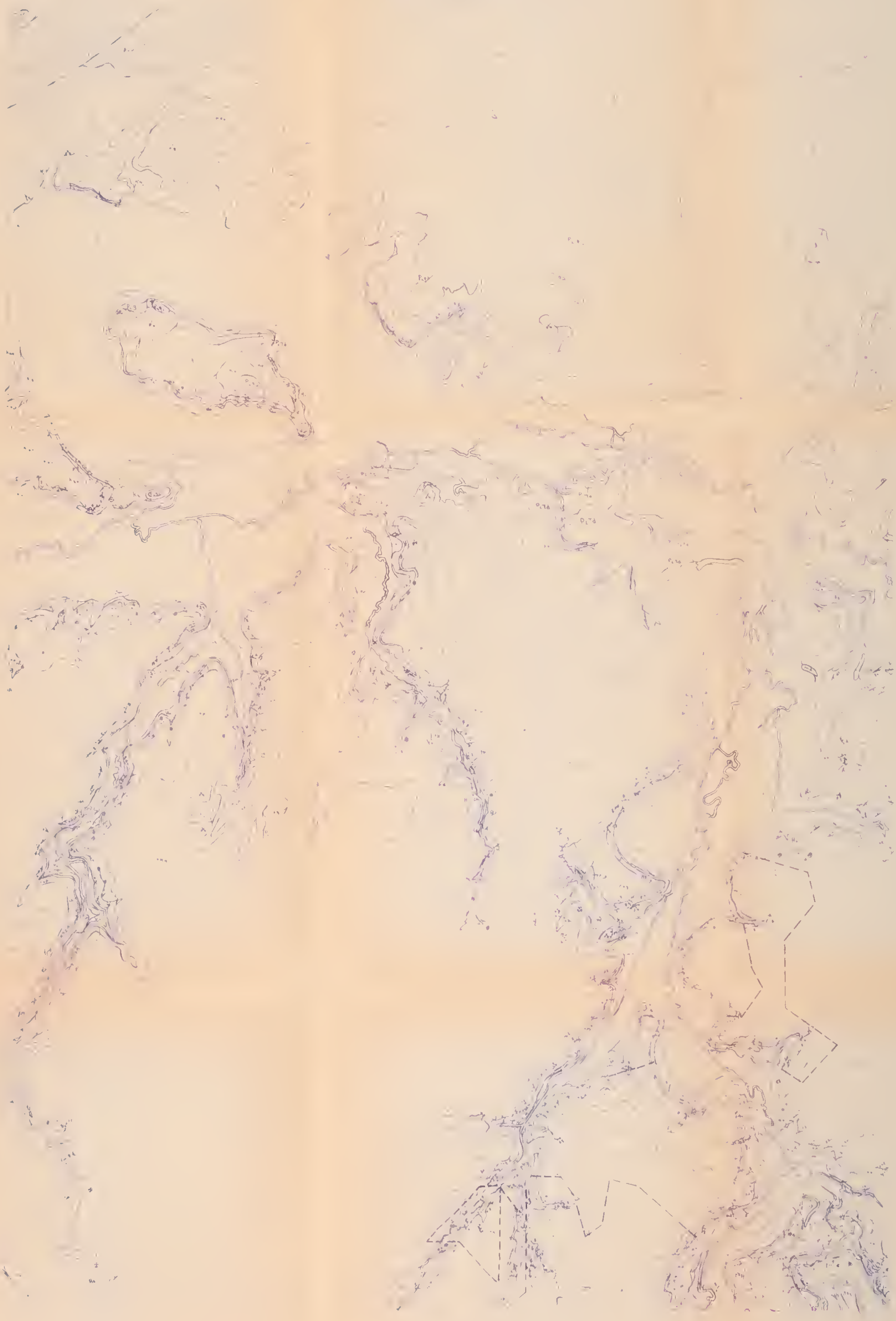
------------------------------MISSISSIPPIAN------------------------------

Mo OTTER FORMATION--Occurs only in southern part of Stockett 7 1/2-minute quadrangle. Bright green and gray fissile shale with interbedded thin, platy micrite beds containing algal structures and thin black chert beds. At least twenty m exposed in southeast corner of Stockett 7 1/2-minute quadrangle.

Mm MISSION CANYON LIMESTONE--Only upper 30 m is exposed in map area. Dominantly medium gray micrite containing stromatolites, solution breccia and black chert nodules and beds up to 10 cm thick. Crinoids, brachiopods, coral and bryozoan are present locally.

Geologic map of the southeast Great Falls Quadrangle, Montana

PLATE 2A



SYMBOLS

- Strike and dip of inclined bedding
- Horizontal bedding
- Contact
- Fault
- Outline of known underground mine workings
- Mine dump
- Landslide

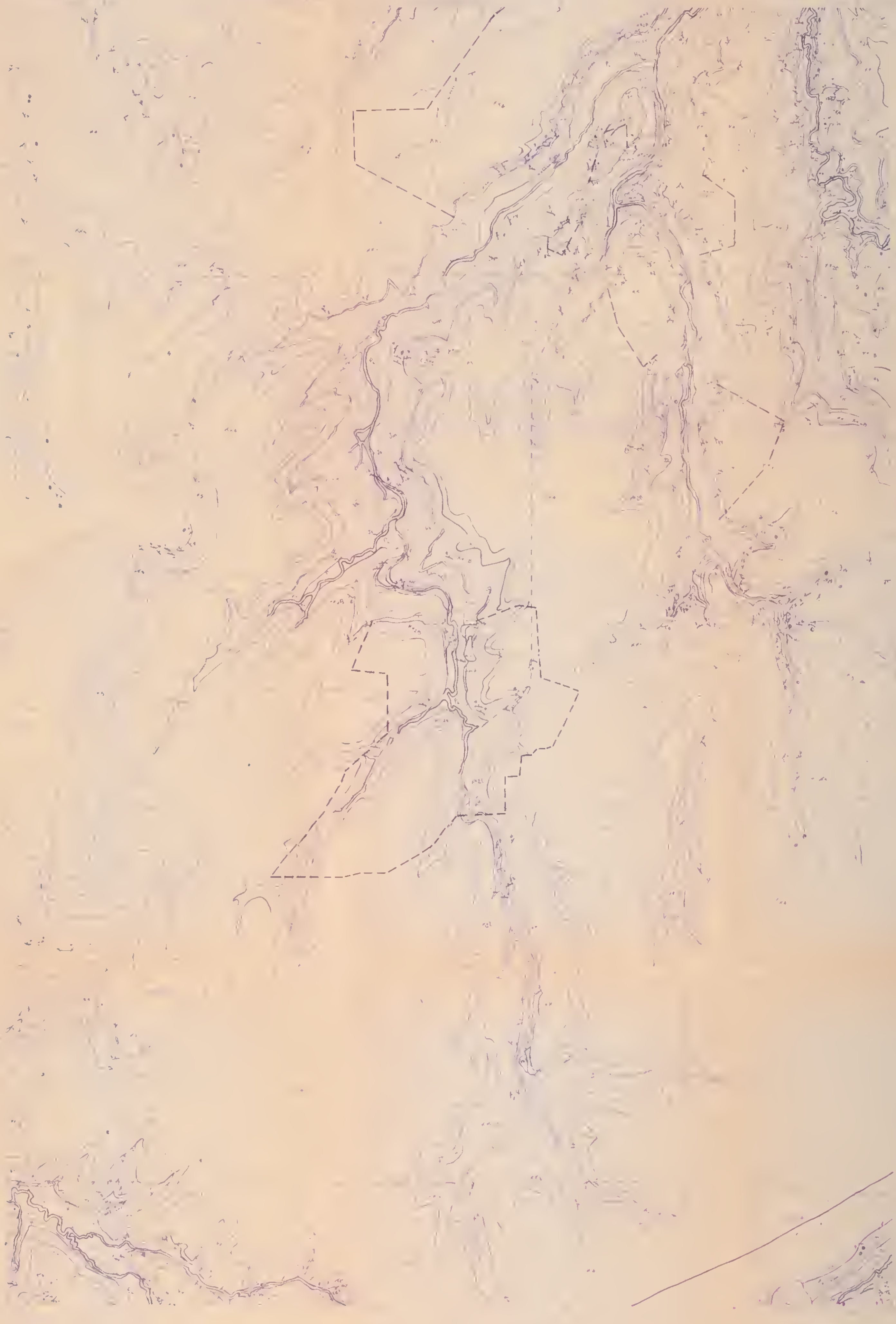
P_1l	OLDER LACUSTRINE BEDS
P_1g	HIGHER GRAVEL DEPOSITS
Kbf	BLACKLEAF FORMATION
Kk_4	KOOTENAI FORMATION
Jm	MORRISON FORMATION
Js	SWIFT FORMATION
Mo	OTTER FORMATION
Mm	MISSION CANYON FORMATION

by

N. S. Williams, R. C. Murray, S. M. Vuke-Foster and M. J. Bartholomew

Geologic map of the Stockett Quadrangle, Montana

PLATE 2B



SYMBOLS

- Strike and dip of inclined bedding
- Horizontal bedding
- Contact
- Fault
- Outline of known underground mine workings
- Mine dump
- Landslide

Hal	ALLUVIUM
Hcl	COLLUVIUM
He	EOLIAN DEPOSITS
$P_L t$	TILL
PLl_1	LACUSTRINE BEDS
$P_L td$	TERRACE DEPOSITS
$P_L g_1$	LOWER GRAVEL DEPOSITS
$P_L l_2$	OLDER LACUSTRINE BEDS
$P_L g_2$	HIGHER GRAVEL DEPOSITS
Kbf	BLACKLEAF FORMATION
Kk_5	
Kk_4	KOOTENAI FORMATION
Kk_3	
Kk_{2A}/Kk_{2B}	
Kk_1	
Jm	MORRISON FORMATION
Js	SWIFT FORMATION
Mo	OTTER FORMATION
Mm	MISSION CANYON FORMATION

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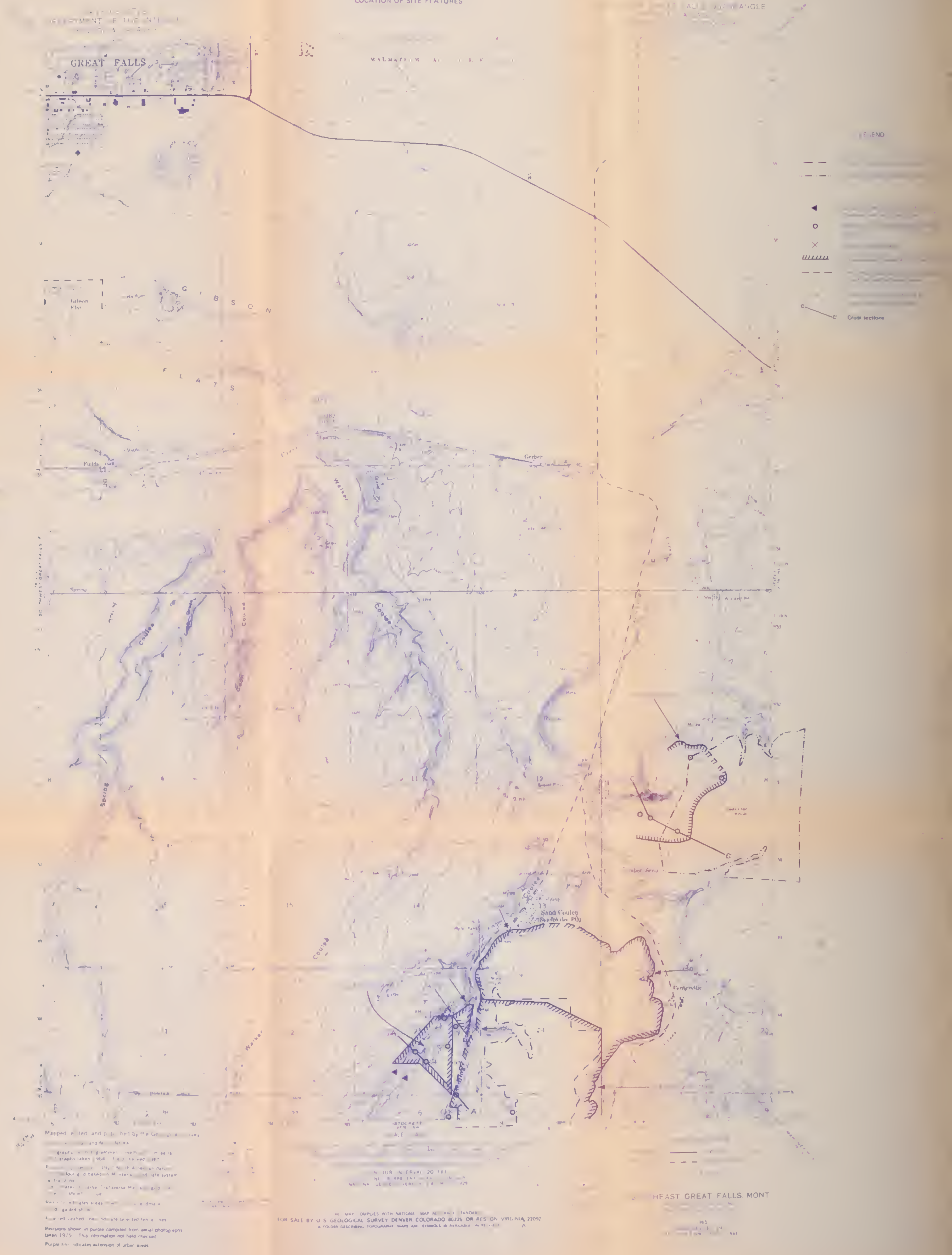
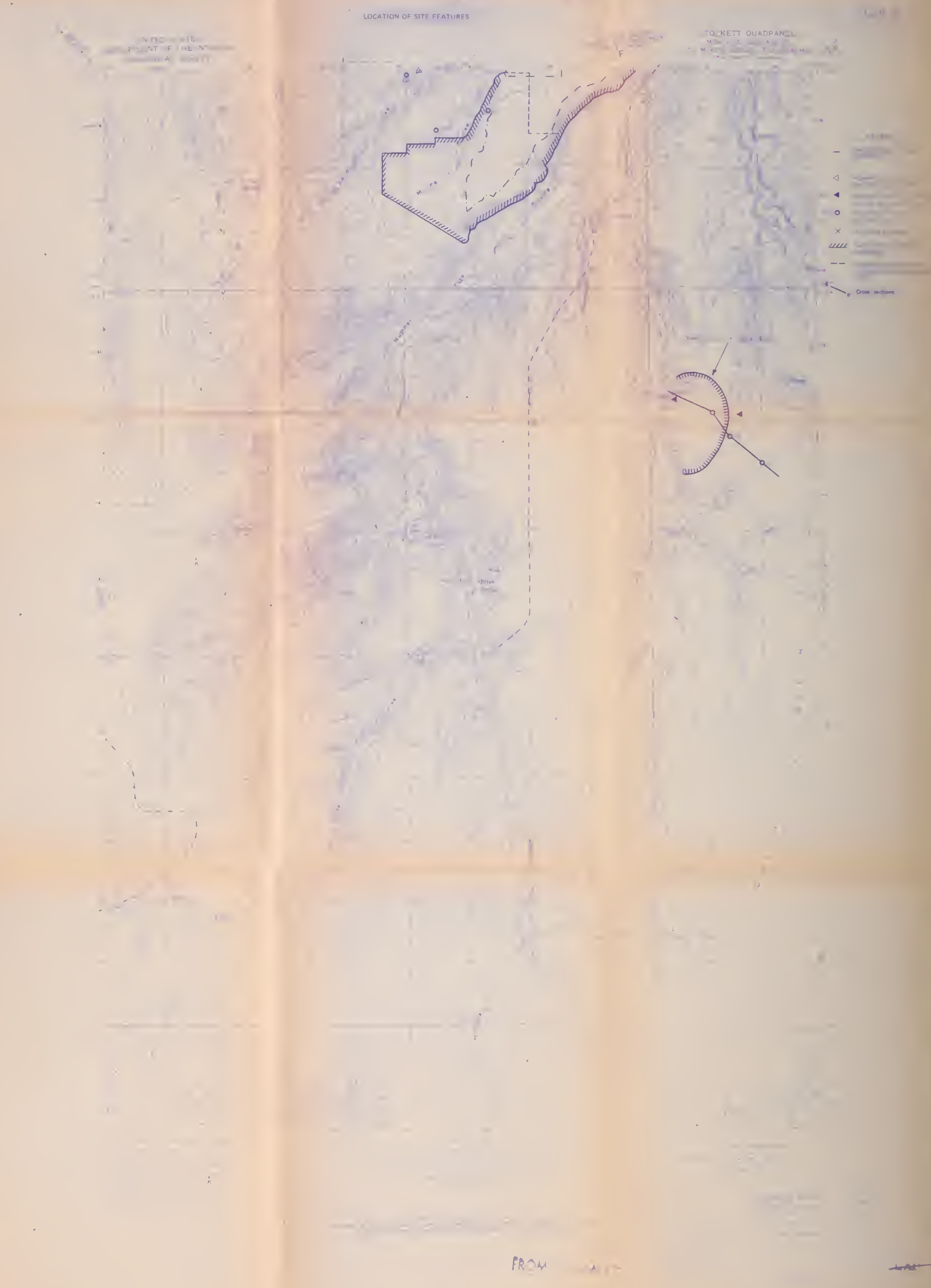


LOCATION OF SITE FEATURES



LOCATION OF SITE FEATURES
Cross sections
FROM